The Association
OF
Engineering and Shipbuilding Draughtsmen.

The Working and Design of Gas Producers.

By

J. W. SPEDDING (Member).

TECHNICAL SECTION.

SESSION 1922-23.

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THE WORKING AND DESIGN OF GAS PRODUCERS.

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INTRODUCTION.

In modern iron and steel works in this country where no large sources of natural gas have yet been found, gas producers are, no doubt, one of the most useful and essential portions of the plant. There is nothing more conducive to the satisfactory working of steel-melting and regenerative furnaces generally than the economical production of good producer gas. Gas producers are the machines used for this purpose, being that section of the plant where the raw fuel is converted as far as possible into combustible gas, which can be readily conveyed to any part of the works in suitable flues. In treating a subject such as this within the limits of a technical paper it will be more satisfactory to confine my remarks to one class of producer only, giving a concise description of present-day practice and design, without going into the relative merits of the various makes of gas producers put forward by their respective manufacturers.

The first attempt to make producer gas was by Bischof, about the year 1839. He employed a cylindrical brick chamber, having a firebar grate, introducing air with natural chimney draught, using peat as fuel. It was not until Siemens Brothers, however, invented their gas producer about the year 1861 that gas producers became a commercial success. At the present day there are innumerable varieties of gas producers on the market, each differing from the other in certain details, but all developments from the Siemens producer, aiming rather at greater economy and quicker working than at any radical alteration to fundamental principles.

DESCRIPTION.

The type of gas producer used in iron and steel works is usually that of the improved Siemens type. The ammonia recovery type is not in such general favour because it delivers a gas having a large amount of carbon dioxide and hydrogen in its composition, whilst being highly saturated with water vapour. This occurrence is due to the great quantity of steam necessary for ammonia recovery, which reduces the temperature of the producer below the point of complete dissociation, leaving a gas with a high hydrogen content

and highly saturated with water vapour which does not give the high temperatures required for certain metallurgical operations. The radiation of heat from a carbon monoxide flame is $2\frac{1}{2}$ times greater than that from a hydrogen flame of the same dimensions, while the water vapour absorbs part of the heat due to the combustion of the other gases.

The ammonia recovery producer has not met with much favour. although it has advantages when a large number of furnaces of relatively small gas consumption, and spread over a large area, can be supplied from one gas-producing battery. The gas mains can also be of lighter construction and smaller diameter, and do not require to be lined with brickwork as the gas is delivered to the mains at a low temperature.

The disadvantages of this system are the high initial cost, the large quantity of steam required in the producer per ton of fuel gasified, and the expense involved in removing the excess steam from the gas before combustion. Gas from the ammonia recovery producers as mentioned differs from that of other producers in its large content of carbon dioxide, water vapour and hydrogen. Water vapour is usually given as the cause of increased scaling in re-heating work, but water vapour in any insufficiently cooled gas is always a contributory cause.

Gas producers of the former type, which alone will be dealt with, can be classified under two headings, viz. :—

1. Gas producers worked with natural draught (but as this class of producer has practically died out they will not be considered).

2. Gas producers worked with forced draught, usually produced by means of a steam jet, although a fan is sometimes used.

These two classes can be further sub-divided thus :—

    A. Producers with firebars.
    B. Producers with dry bottoms.
    C. Producers with wet bottoms or water-sealed bottoms.

Gas producers coming under Class 2 being those which are now largely employed in modern iron and steel works, this class only will be dealt with in this paper.

Fig. 1 shows the general arrangement of a modern Siemens gas producer. This is a typical example of a forced draught producer with a firebar bottom. As can be seen, it takes it name from the fuel resting on the firebar grate, forced draught being supplied by means of a steam jet underneath the grate, which forces the air into the closed ashpit and so through the fuel in the producer.

"SIEMENS" PRODUCER WITH FIREBAR GRATE
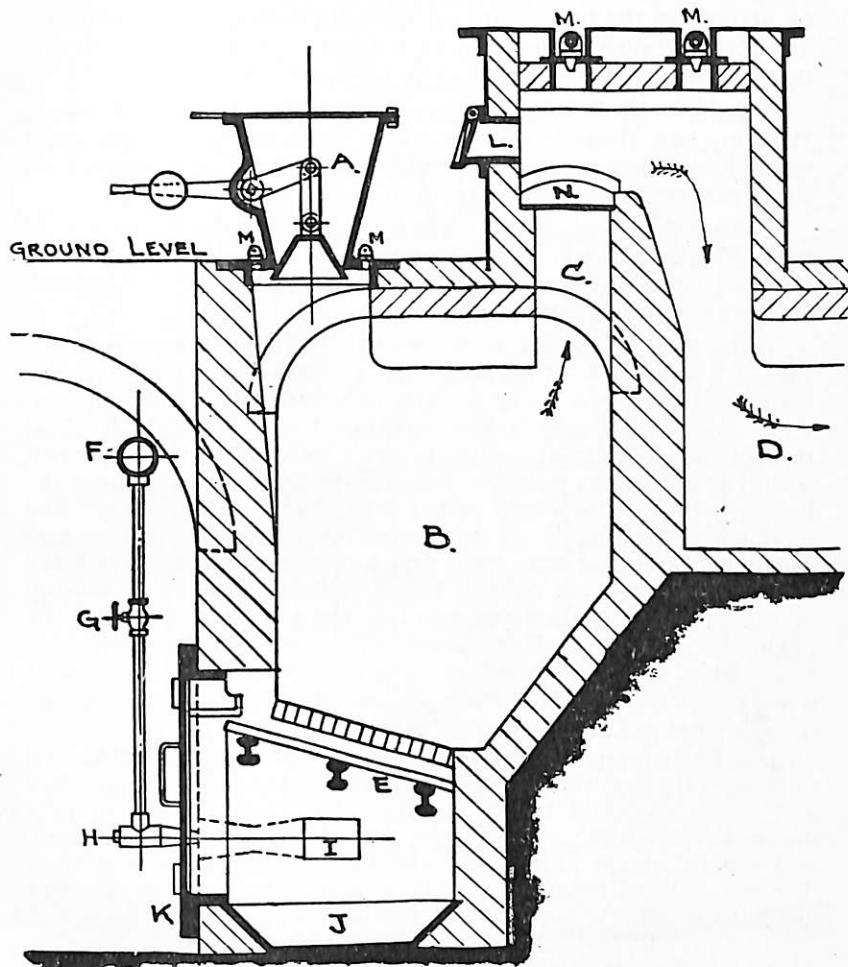
A. CHARGING HOPPER.
B. CHAMBER.
C. GAS OUTLET.
D. GAS FLUE.
E. FIREBARS.
F. STEAM MAIN.
G. STEAM REGULATING VALVE.

H. STEAM NOZZLE.
I. AIR INLETS.
J. ASH PIT WATER BOSH.
K. ASH PIT CLEANING DOOR.
L. EXPLOSION DOOR.
M. POKING HOLES.
N. DAMPER.

FIG. 1.

Fig. 2 shows the general arrangement of a modern Wilson gas producer of the forced draught solid bottom type, a name given on account of the fuel resting on the solid bottom of the producer. The forced draught is supplied by a steam jet, which carries the air into the fuel bed by means of a central tuyere or distributor.

Figs. 3, 4, and 5 show general arrangements of modern Dowson, Wincott, and Wellman gas producers respectively, and are good examples of the forced draught, water sealed bottom gas producer, the types now very largely employed in iron and steel works.

Gas producers of the types shown in Figs. 1 and 2 are not so popular as there is a great loss in efficiency and irregularity in working, due to the necessity of shutting off the blast from the producer every time the ash requires cleaning out.

A detailed description of the construction of the types shown on Figs. 3, 4 and 5 may prove acceptable to those who are not familiar with them. The producer consists of a cylindrical shell made of mild steel plates and angles rivetted together. This is lined throughout with a hard quality firebrick to form the hearth, which should be suitable for resisting the abrasion due to the charging of the fuel into the producer and pokers striking the brick lining. The producer is best made of circular section, thus avoiding corners where ash or clinker may lodge and form air channels through the fuel bed. Corners are difficult to get at from the holes on the top of the producer if good judgment is not exercised in fixing the poking holes in a suitable position. The casing of the producer is mounted on top of a water-bosh or pan, and is carried down about 6 ins. below the water level to make an effective water seal against the escape of gas at that point. Air is forced into the producer by means of a steam jet through a diverging blower, and is distributed to the fuel through the cross grid in the case of the Dowson producer and through central tuyeres in the Wincott and Wellman producers. The outlet for the gas is placed near the top of the casing, and usually at the side, where the isolation gas valve is placed. This is usually of the mushroom type, and is actuated by means of a balance weight, or screw and handwheel. This valve is to enable the producer to be shut off independently from the main gas flue. About 2 ft. 3 ins. to 3 ft. above the water seal, sight holes are provided, so that the producer men can watch the zone of combustion and thus be enabled to correct the irregularities of level, also to enable them to introduce bars to remove clinker from the grates. In the centre of the top of the producer is placed the charging hopper, which is kept gastight by the conical bell fixed into the bottom of the hopper, the fuel being fed into the hopper either by hand or from overhead bunkers. Mechanical or hand methods can be used for feeding the fuel into the producer, but whichever system is used care must be taken to have the fuel evenly distributed over the whole area of the

"Wilson" Producer with Solid Bottom.
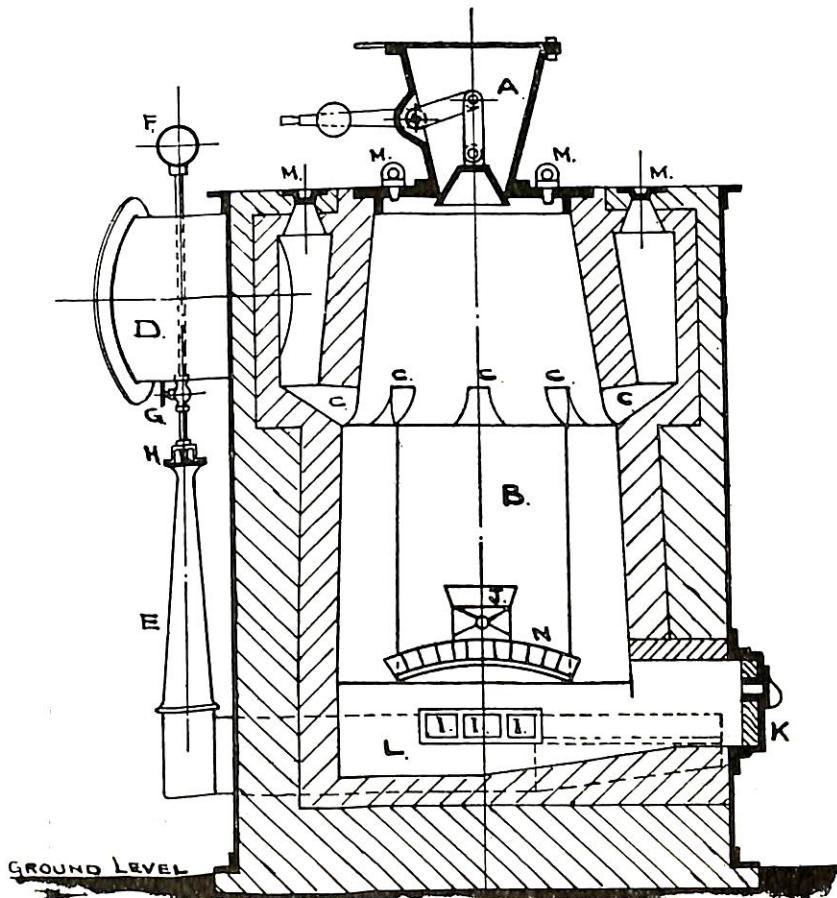
A. Charging Hopper.	H. Steam Nozzle.
B. Chamber.	I. Air Inlets.
C. Gas Outlets.	J. Air Distributer.
D. Gas Flue.	K. Ash Pit Cleaning Door.
E. Steam Blower.	L. Ash Pit.
F. Steam Main.	M. Poking Holes.
G. Steam Regulating Valve.	N. Distributer Arch.

Fig. 2.

"DOWSON" WATER BOTTOM PRODUCER.

FIG. 3.

'WINCOTT' WATER BOTTOM PRODUCER

CHARGING HOPPER

POKING HOLES

GAS OUTLET

HEARTH

FIRE BRICK LINING

STEAM NOZZLE

SIGHT HOLES

BLOWER

WATER BOSH

FLOOR LEVEL

CLEANING DOOR

HEARTH

AIR TUYERE
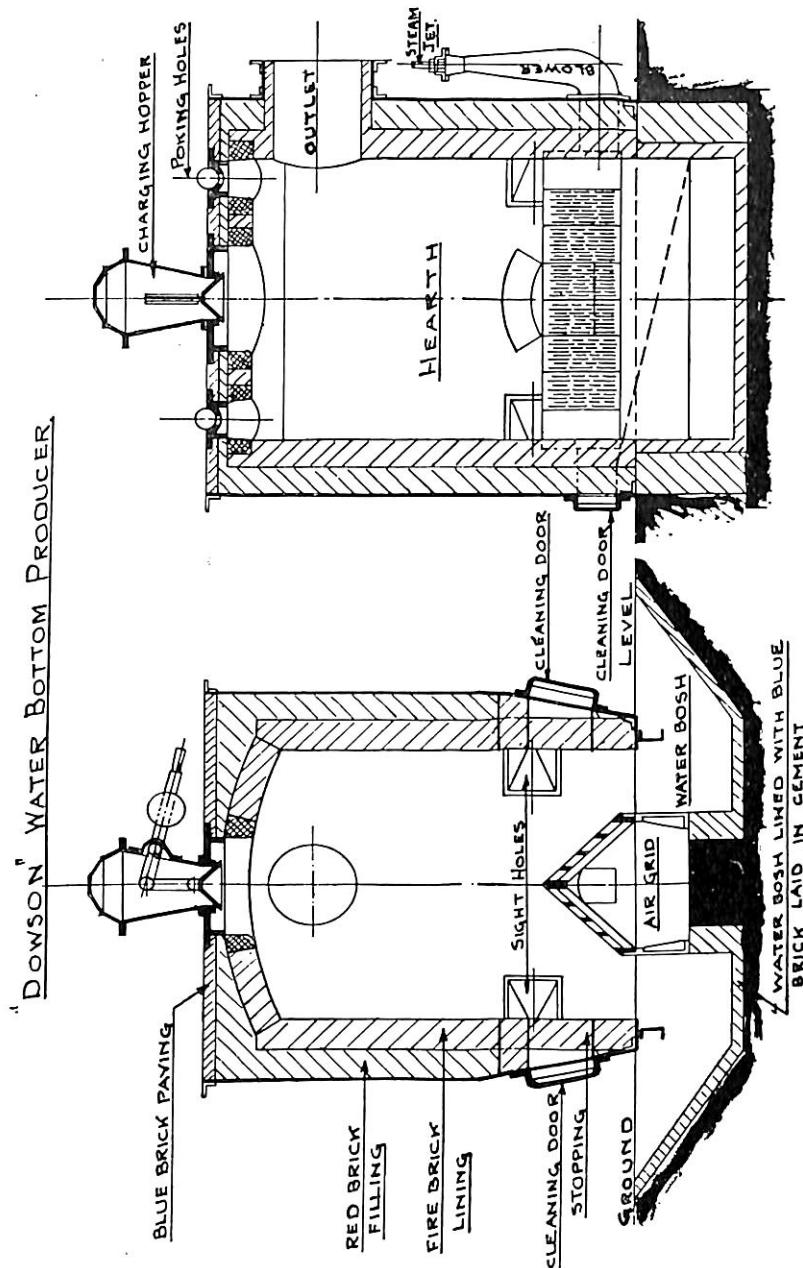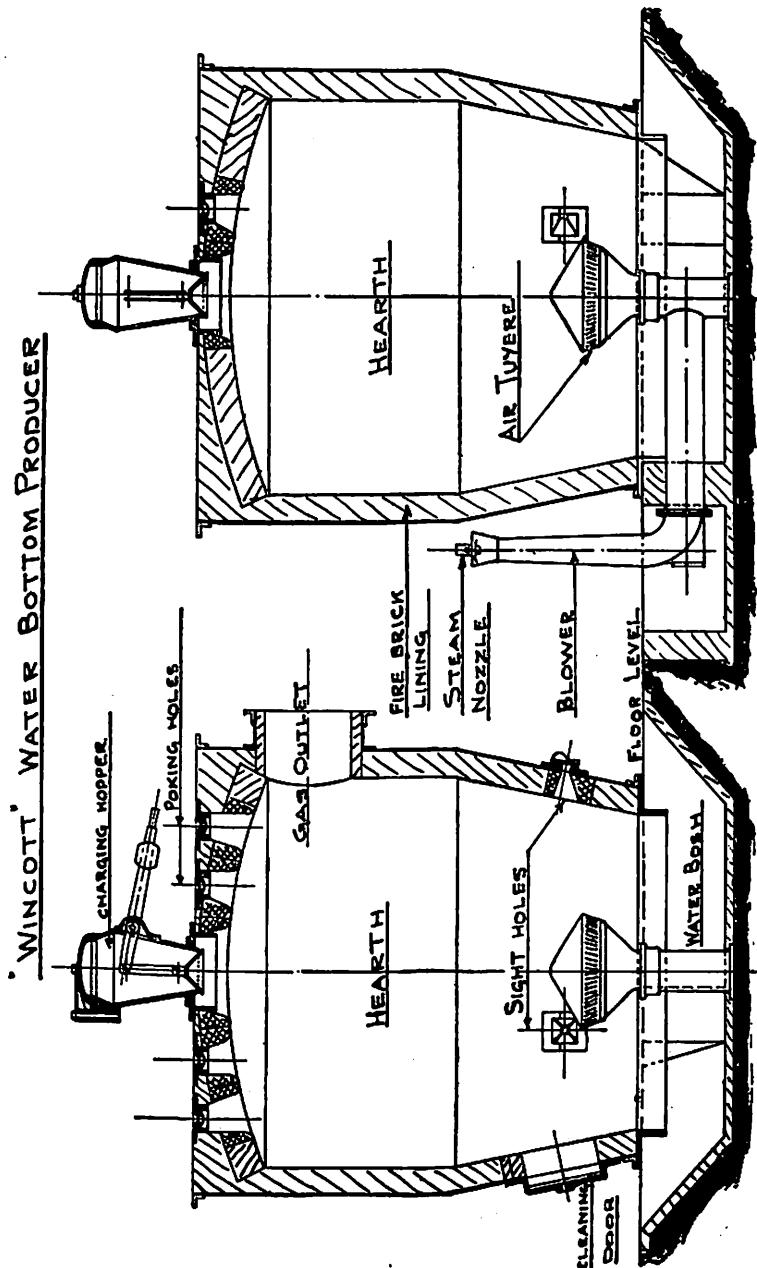
FIG. 4.

producer, and this to a great extent depends upon the correct design of the charging bell.   On the top of the producer four or six poking holes are provided, placed in such a position that they give access to the whole hearth, especially the sides of the producer, as the tendency of the clinker is to adhere there.   These are to enable the men to poke down the fuel and fill up any air channels that may develop in the fuel bed, and break down the clinker.   Cleaning doors are provided in the sides of the producer about level with the sight holes at the combustion zone to facilitate cleaning out when the producer is shut off.   It is sometimes necessary at the end of a run to break up large clinkers which have formed, and these would be difficult to get out through the water-bosh in the ordinary way.   These doors are also used to facilitate lighting up the producer when starting a new run.
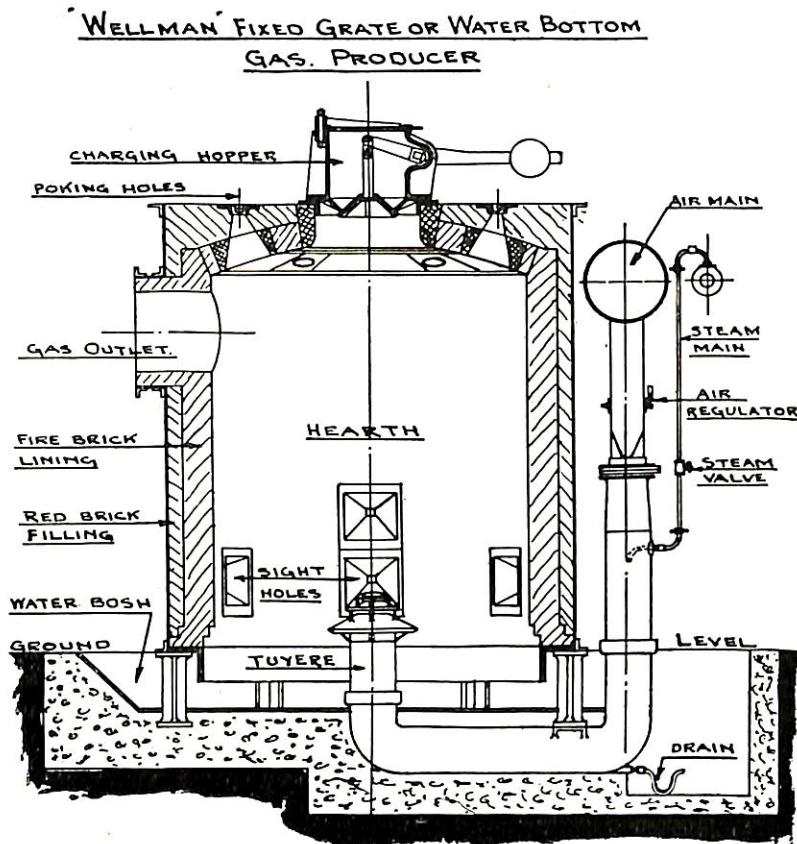

FIG. 5.

Working the Producer.

1. The object of a gas producer is to gasify the fuel as completely as possible into hot combustible gases leaving less than 1 per cent. of the original carbon in the ash.

2. The production of a gas containing the lowest possible percentage of nitrogen (N) and carbon dioxide (CO_2), as both these gases are inert and useless for combustion purposes.

3. To deliver gas of equal uniformity as regards quality, quantity and temperature.

The working of a gas producer is a simple operation if certain rules are carried out, the chief essentials being :—

(1) Sufficient care by the man in charge to see that the fuel is charged regularly and distributed evenly over the whole area of the producer.

(2) To keep the clinker broken up and regularly cleared away with the ash.

The formation of clinker is the worst feature in the working of a producer, but it can be considerably avoided by a correct steam distribution. Regular firing of the fuel into the producer with the object of maintaining a good level bed of fuel also assists. If the latter be not done, pockets or channels form through which the blast cuts its way, with the result that the gases begin to burn inside the producer which melts the ash and forms masses of clinker. The burning of the gas at the same time increases the percentage of carbon dioxide (CO_2), leaving the producer, with the consequent lowering of efficiency and the production of an over-heated gas. It is thus seen that conditions which produce clinkering also increase the percentage of carbon dioxide (CO_2). There is always a certain amount of carbon dioxide (CO_2), formed in the gas producer which is inevitable, but if it does not exceed more than about 4 per cent. it is not a dead loss in efficiency, as part of the calorific value of the fuel so burned is represented in the sensible heat of the gas and hot gas is thereby delivered to the furnaces. If more than 4 per cent. of carbon dioxide (CO_2) is formed the efficiency of the gas produced drops quickly, as the temperature of the gas becomes so great that the hydrocarbons decompose and deposit carbon (C) in the form of soot, also the loss from radiation becomes correspondingly greater. If the gas producer is worked at too cool a temperature by admitting too much steam or by too frequent firing, the result is equally bad, because the volatile tars distilled from the fuel condense and deposit in the flues. This reduces the heating value of the gas, as the tar can be effectively burned in the furnaces if the gas be not cool enough to allow it to condense before it gets there. The best result is obtained from

a producer when the carbon dioxide (CO_2) in the gas, is kept about 4 per cent. and the out-going gas temperature is from 1,100° to 1,200°F.

Fig. 6 shows a chart giving the percentage of heat value of the coal lost in burning the gas in the producer, when forming various percentages of carbon dioxide (CO_2) in the gas.

Fuel.—Gas producers can be designed for gasifying any type or class of fuel, but if a good quality of gas be required and economical production sought after, it is necessary to use as high a quality of fuel as it is possible to obtain. For moderate furnace temperatures up to about 2,200°F. an ordinary anthracite or semi-bituminous class of coal may be used, but for high temperatures such as are required in open hearth steel melting furnaces and some reheating furnaces, a high-class of non-caking bituminous coal is necessary. It is imperative that when high temperatures are required, the fuel should not only have a high percentage of fixed carbon, but also a high percentage of volatile matter in its composition. A high grade bituminous coal fulfils these conditions, and when gasified gives a highly luminous flame on combustion which intensifies the radiation from the roof of the furnace, also the heating effect can be controlled and concentrated on a smaller area. The chief factors in good gas coal, as mentioned, are uniformity in size, freedom from caking, ash of high melting point, also the quantity of fixed carbon and volatiles, the former varying between 40 and 55 per cent., and the latter from 25 to 40 per cent. These latter form the total combustibles when gasified. All fuels contain other ingredients such as sulphur, chlorine, phosphorus, moisture and mineral matter which form the ash. Sulphur, if possible, should never form more than 1 per cent., because it usually occurs in the form of iron pyrites ($Fe.S_2$), which is an easily fusible substance and when in this state forms a molten binder or nucleus around which clinkers are formed. It also increases the sulphur in steel when the gas is used for melting furnaces. The percentage of ash in the fuel should be as low as possible, about 5 per cent. being not an excessive figure. It is obvious that the higher the percentage of ash the greater the working costs will be and the lower the efficiency of the producer. If caking fuels are employed it will be necessary to fit mechanical stirrers to break up the cake which forms on the producer fuel bed.

Fig. 7 is a chart showing the percentage of the total heat value of the fuel lost with varying proportions of ash, and varying percentages of carbon (C) left in the ash drawn from the producer.

The fuel used in gas producers should not be either too large or too small, and should be uniform in size, the best size being what is called run-of-mine, so named because it is crushed at the

CHART SHOWING PERCENTAGE OF TOTAL HEAT VALUE OF FUEL LOST
ACCORDING TO PERCENTAGE OF CO2 IN GAS.

CAMPBELL

PERCENTAGE OF CO2 IN GAS

PERCENTAGE OF HEAT VALUE LOST
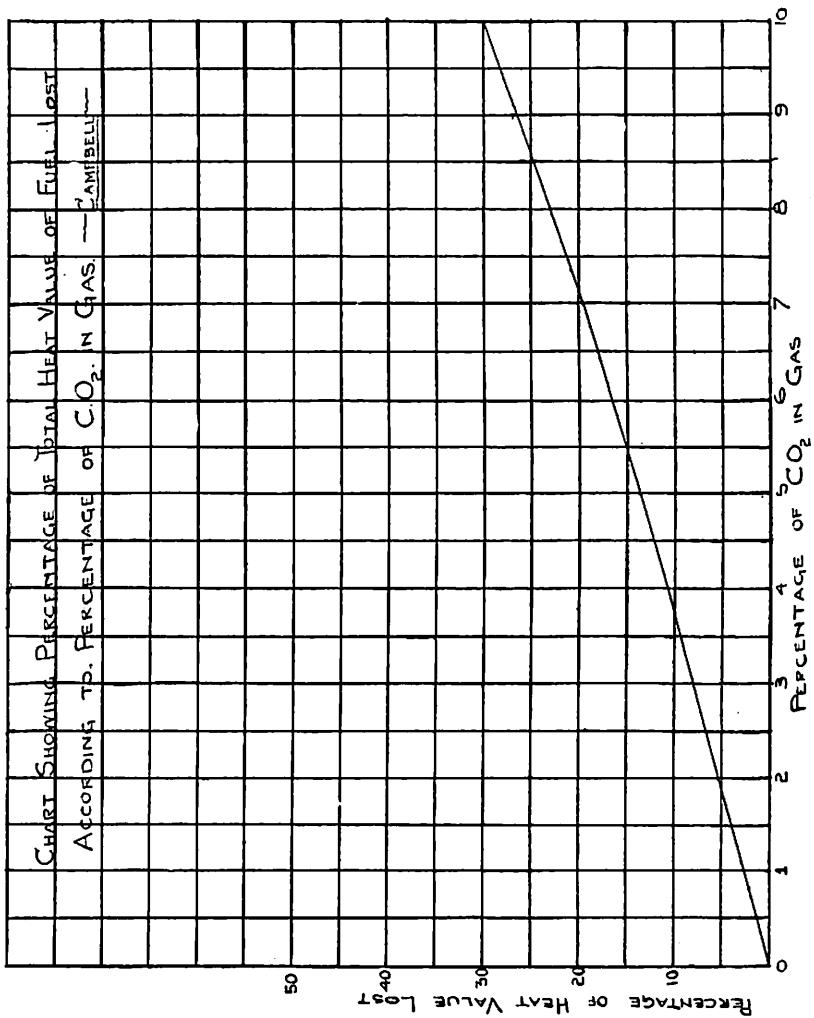
FIG 6.
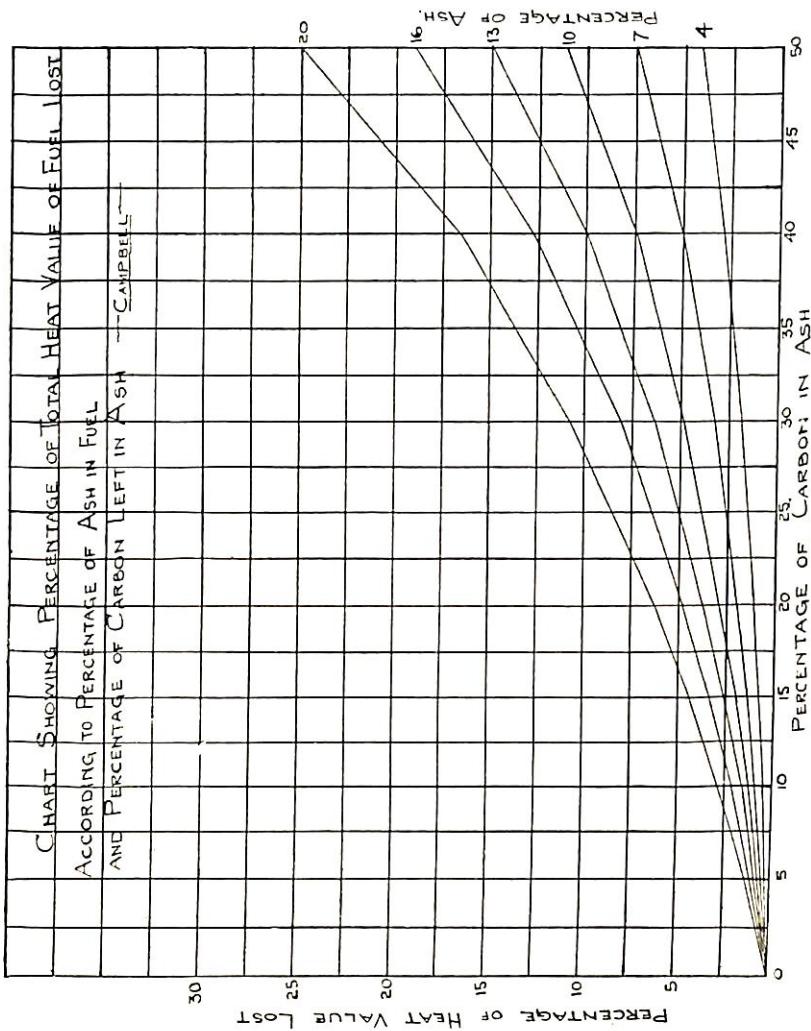
FIG. 7.

Table giving Average Analysis of Three Classes of Coal. Also Average Ultimate Analysis and Average Ash Analysis.

Constituent	High Quality Coal			Low Quality Coal			Average Quality Coal		
	Anthracite	Semi Bituminous	Bituminous	Anthracite	Semi Bituminous	Bituminous	Anthracite	Semi Bituminous	Bituminous
Water %	1·00	1·00	1·00	2·00	3·00	4·00	1·50	2·00	2·50
Volatiles %	5·00	18·00	40·00	5·00	15·00	34·00	5·00	16·50	37·00
Fixed Carbon %	88·50	76·50	53·50	75·00	67·00	46·50	81·75	71·25	50·00
Sulphur %	·50	·50	·50	2·00	3·00	3·50	1·25	1·75	2·00
Ash %	5·00	5·00	5·00	16·00	12·00	12·00	10·50	8·50	8·50
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Combustables %	94·00	94·00	94·00	82·00	85·00	83·50	89·00	90·50	89·00
Waste Gases %	1·00	1·00	1·00	2·00	3·00	4·00	1·50	2·00	2·50

Average Ultimate Analysis of Coal.

Carbon	Hydrogen	Oxygen and Nitrogen	Sulphur	Ash	Water
C	H	O N	S		H_2O
82·246	5·156	7·946	1·295	3·387	-

Average Ash Analysis.

Silica	Alumina and Ferric Oxide		Lime	Magnesia	Sulphuric Acid	Phosphoric Acid
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	H_2SO_4	H_3PO_4
49·77	38·35		3·18	1·41	6·26	1·03

Fig. 8.

mine to pass a 4 ins. ring or mesh. If desired $1\frac{1}{4}$ ins. to 2 ins. screened nuts may be used very satisfactorily. It is not advisable to use slack for producers as it only chokes the blast, which results in an overheated gas with the consequent loss in efficiency and other troubles arising therefrom. This is due to having to work with a shallower combustion zone, consequently the CO_2 formed in the first instant has less opportunity of being converted to CO before leaving the fuel bed.

Fig. 8 is a table giving the average analysis of the three classes of coal mentioned above, also the average analysis for the ash.

Action within the Producer.—As the designing of gas producers falls to the lot of the engineer, it is essential that he should be as familiar with the chemical and thermal actions that take place within the producer as the chemist or metallurgist, if he intends to try and produce an efficient machine. A brief outline of what takes place in the producer is given in the following paragraphs.

Fig. 9 shows the cross section of a gas producer when at work. In the bottom of the producer is a bed of ash upon which the layer of fuel to be gasified rests. This fuel bed can be split up into three distinct zones, namely, the combustion zone immediately above the ash bed, the coking zone above that, and the distillation zone at the top. When the producer is in action the bed of ash is kept about 2 ft. 6 ins. to 3 ft. high, on a level with the sight holes in the shell, thereby keeping the blast tuyere protected from the heat of the combustion zone. The chemical reactions taking place are as follows : In the combustion zone which is the layer of incandescent coke or carbon immediately above the ash, commencing at the sight holes and extending up the producer, the white hot coke or carbon comes into contact with the mixture of air and steam, which has been superheated previously in passing through the hot bed of ash. It combines with the oxygen (O) of the air (N+O) and that of the steam (H_2O), thus forming carbon dioxide (CO_2), at the same time liberating hydrogen (H) from the steam, the nitrogen (N) from the air takes no part in these reactions and is therefore unaffected. Thus in the combustion zone two chemical reactions are taking place, *i.e.* :—

1. (C+O_2 from air=CO_2+N from air) (formation of carbon dioxide from carbon and atmospheric oxygen).

2. (C+$2H_2O$=CO_2+$2H_2$) (formation of carbon dioxide and hydrogen from carbon and steam).

The carbon dioxide (CO_2), the hydrogen (H), and the nitrogen (N) immediately pass upwards through the coking zone, where the carbon dioxide (CO_2) comes into contact with the red hot coke or carbon (C), and takes therefrom another atom of carbon (C)

Arrangement of "Dowson" Producer at work.

A, Ash Bed.
B, Combustion Zone.
C, Coking Zone.
D, Distillation Zone.
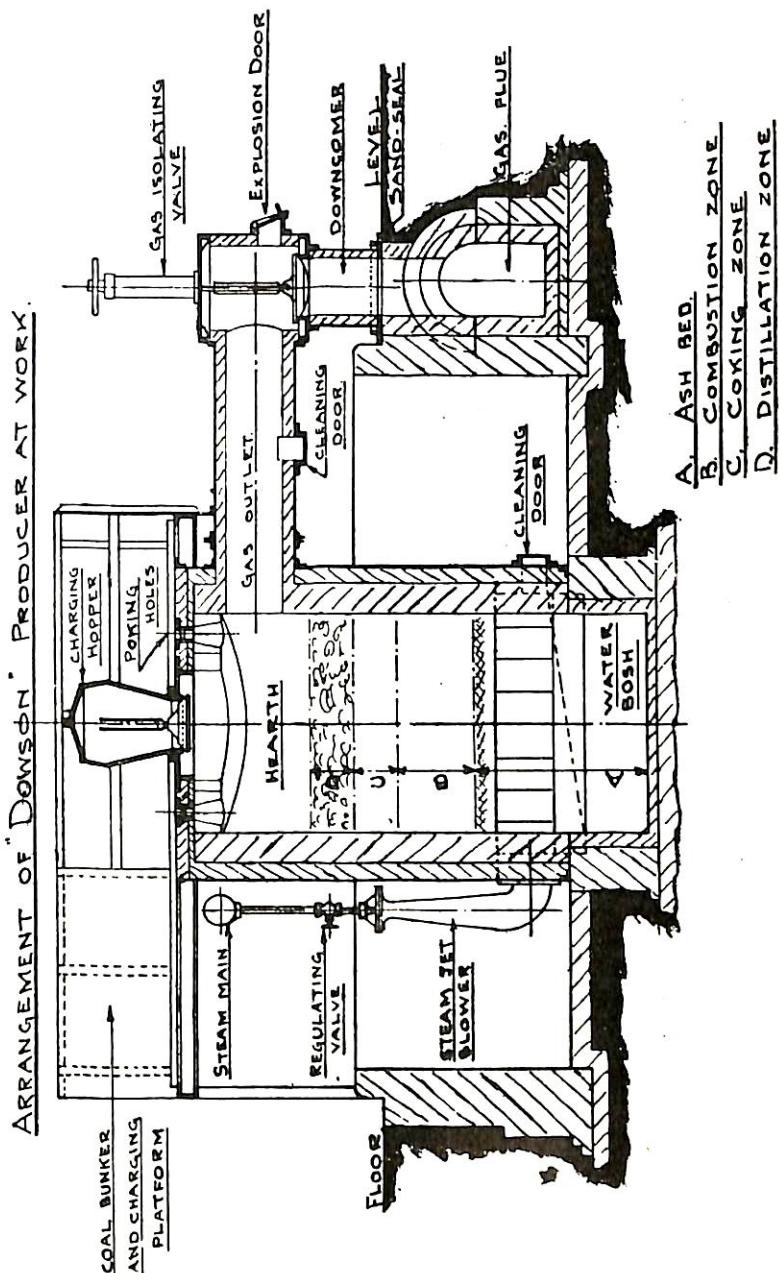
Fig. 9.

forming carbon monoxide (CO) according to the equation $CO_2 + C = 2CO$. Some of the hydrogen (H) may unite with some of the carbon (C) forming methane (CH_4). If the temperature be suitable in the producer, nitrogen (N), being an inert gas, simply passes through without any change taking place in its composition. Thus in the coking zone two chemical reactions may be taking place, *i.e.* :—

1. $CO_2 + C = 2CO$.
2. $2H_2 + C = CH_4$.   (If temperature be suitable.)

The gases formed in the coking zone next pass upwards into the distillation zone, thus heating up the raw fuel to a high temperature which liberates the volatile gases and vapourises the tarry matter contained in the fuel. The foregoing are the principal chemical reactions that take place in the producer, the resultant gas which leaves it, being a mixture containing carbon monoxide (CO), hydrogen (H), methane (CH_4) and ethylene (C_2H_4) and other hydrocarbons which form the combustible constituents, together with carbon dioxide (CO_2) and nitrogen (N) the non-combustibles. The last named is, of course, inevitable so long as atmospheric air has to be used for producing combustion. In addition to the foregoing reactions, certain minor, but nevertheless important reactions occur simultaneously, due to the fact that the fuel usually contains other constituents of a non-carbonaceous nature. Briefly they are as follows :—

All fuels contain from 2 per cent. to 15 per cent. of water, usually hygroscopic, but some of it chemically combined, and when this is heated up it becomes evaporated into steam which mixes with the other gases, leaving the producer. Sulphur occurs in coal to the extent of $0 \cdot 5$ per cent. to 3 per cent. and is combined in at least three forms, the commonest and most objectionable being in that of iron pyrites $(Fe.S_2)$ (ferrous disulphide). When this is burned it forms oxide of iron (Fe_2O_3) which comes away in the ash, and sulphur dioxide (SO_2) which escapes with the producer gas, thus $(4Fe.S_2 + 11.O_2 = 2Fe_2O_3 + 8SO_2)$. If only heated without excess of air, then the pyrites split up into iron sulphide (FeS) which remains in the coke, and sulphur (S), thus $(FeS_2 = FeS + S,)$ the latter then combines with the carbon (C) to form carbon disulphide (CS_2) which escapes with the producer gas. Some sulphur is also in the form of calcium sulphate $(CaSO_4)$ in coal, and is another objectionable form, because when heated to a high temperature with excess of carbon (C) it is decomposed and calcium sulphide (CaS) is left, and the liberated oxygen (O) combines with the carbon (C) and forms carbon monoxide which comes away in the gas, thus $(CaSO_4 + 4C = CaS + 4CO)$.

Chlorine (Cl) is always present in coal but is of no importance to the metallurgist although it is of vital importance to the engineer.

It varies from ·06 per cent. to ·2 per cent. and is chiefly in the form of sodium chloride (NaCl) (common salt). This, when burned is decomposed by the silica (SiO_2) in the ash, liberating either chlorine (Cl) or hydrochloric acid (HCl), usually the latter, which has a highly corrosive action on brass or copper tubes and plates. Hence its importance when coal is used for firing tubular boilers, etc.

Phosphorus (P) is always present in coal and varies from ·1 per cent. to 1·25 per cent., and is usually in the form of calcium phosphate $Ca_3(PO_4)_2$. This when heated is attacked by sulphuric acid, which is formed by a further reaction on the calcium sulphide (CaS), and converts it into calcium sulphate ($CaSO_4$) and phosphoric acid (H_3PO_4), thus [$Ca_3(PO_4)_2 + 3H_2SO_4 = 3CaSO_4 + 2H_3PO_4$], the whole of which comes away in the ash. The completion of the chemical reactions described above leads to the entire gasification of the combustible constituents of the fuel, and deposition of its mineral matter in the form of ash of the following average composition :—

Silica	...	...	...	SiO_2 ...	49·77%
Alumina and ferric oxide			Al_2O_3 and Fe_2O_3 ...		38·35%
Lime	...	...	...	CaO ...	3·18%
Magnesia...	...	...	MgO ...		1·41%
Sulphuric acid	...	...	H_2SO_4 ...		6·26%
Phosphoric acid		...	H_3PO_4 ...		1·03%

Thermal Actions.—Having dealt with the chemical reactions that take place within the producer, it is now necessary to investigate the thermal actions necessary to bring about these chemical reactions. There are two thermal actions, one exothermic or evolving heat during its course, and the other endothermic or absorbing heat. These occur as the object is to completely gasify all the combustibles in the fuel, which can only be done by the production of heat. In gas producers the whole of the heat for gasification of the fuel has to be supplied by the fuel itself inside the producer, therefore the exothermic action is the heat given out by the combustion of some portion of the fuel in order to maintain the temperature required for gasification of the rest of the fuel. (To this must be added the heat brought into the producer by the steam to get the total heat available in the producer.) It is therefore obvious that the whole of the calorific energy of the fuel and steam can never be represented in the gas obtained, also a certain percentage of carbon dioxide is always present. This loss may be anything from 10 per cent. to 30 per cent. of the total calorific energy of the fuel, depending upon the efficiency in design and working of the producer.

CHART SHOWING PERCENTAGE COMPOSITION OF GAS FORMED BY THE ACTION OF AIR ON CARBON AT VARIOUS TEMPERATURES GAS AT 0° C. & 760 $^m/_m$ BAR.

$\{100 - (CO + CO_2)\} = \%$ N. IN GAS

—— NAUMANN & ERNST RESEARCHES——

CO + CO₂

CO

PERCENTAGE OF GASES BY VOLUME

TEMPERATURE IN DEGREES CENTIGRADE
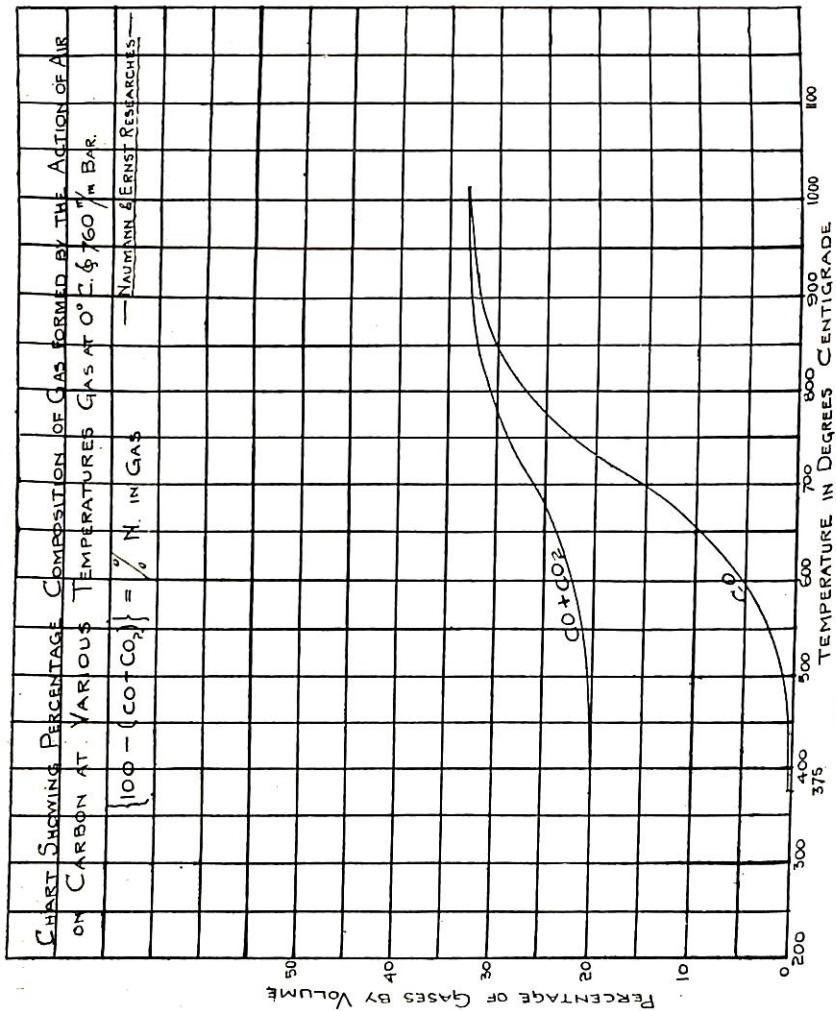
FIG. 10

The endothermic action that takes place is the heat absorbed in decomposing steam by carbon. (To this must be added the heat absorbed and represented as the sensible heat of the gas at the temperature leaving producer, the heat absorbed in raising the temperature of the solid portion of the fuel, the air and the steam from the gas temperature to the combustion zone temperature, the heat absorbed in converting any moisture into steam at atmospheric pressure, and the heat lost due to radiation, conduction, etc., to get the total heat absorbed in the producer.)

Influence of Temperature on Reactions.—The temperatures inside the producer have a very important bearing on the chemical reactions that take place, and also on the efficiency of the gas production. This has been clearly shown from the researches carried out by various investigators.

Fig. 10 shows a chart constructed from particulars of researches carried out by Naumann and Ernst. It will be noticed that when carbon is burned in air to get the reaction ($2C+O_2=2CO$), this reaction commences at a temperature of (375°C.) or (707°F.), but it is not until a temperature of (1,000°C.) or (1,832°F.) is reached, that the whole of the carbon is converted to carbon monoxide, and the formation of carbon dioxide ceases.

Fig. 11 shows a chart, constructed from particulars of researches carried out by Harries, indicating that when carbon reacts with steam to get the reaction ($C+H_2O=CO+2H$), the reaction commences at a temperature of (530°C.) or (986°F.), but it is not until a temperature of (1,125°C.) or (2,057°F.) is reached, that the whole of the carbon is converted to carbon monoxide.

Fig. 12 shows a chart, constructed from particulars of researches carried out by Boudouard, and shows that when carbon dioxide is reduced by carbon to get the reaction ($CO_2+C=2CO$), the reaction commences at a temperature of (530°C.) or (986°F.), but not until a temperature of (1,000°C.) or (1,832°F.) is reached, does the whole of the carbon dioxide get reduced to carbon monoxide. The volatile matter in the fuel is more sensible to the influence of heat than either carbon monoxide or water vapour, and this forms the largest percentage of the distillation gases. As the volatile matter is very valuable for heating purposes, it is necessary that it should not be destroyed, the volatile ingredients begin to be split up at temperatures above (700°C.) or (1,292°F.).

From these particulars it will be obvious that if the producer be required to work under the best gasification conditions, the temperature of the combustion zone should never be allowed to fall below (1,125°C.) or (2,057°F.). At the same time there is no advantage in working at a much higher temperature as it only

CHART SHOWING PERCENTAGE COMPOSITION OF GAS FORMED BY THE ACTION OF STEAM ON CARBON AT VARIOUS TEMPERATURES. GAS AT 0°C & 760 m/m BAR

HARRIS RESEARCHES

$100-(CO+CO_2)$

$\frac{1}{2}$ H. IN GAS

$CO+CO_2$

CO_2

PERCENTAGE OF GASES BY VOLUME

TEMPERATURE IN DEGREES CENTIGRADE

FIG 11.

CHART SHOWING PERCENTAGE COMPOSITION OF GAS FORMED BY THE ACTION OF CARBON DIOXIDE (CO_2) ON CARBON. GAS AT 0°C. & 760 $^m/_m$ BAR.

— BOUDOUARD RESEARCHES —

$(100 - CO) = \% \ CO_2 \ \text{IN GAS}$

PERCENTAGE OF GASES BY VOLUME

TEMPERATURE IN DEGREES CENTIGRADE

FIG. 12.

tends to fuse the ash and form large clinkers, and also increases the losses by radiation, conduction, etc. From the particulars, it is also clear that the temperature of the outgoing gases should never exceed (700°C.) or (1,292°F.), if the volatile hydro-carbons are to be retained, and these observations are confirmed in every-day producer practice. These conditions govern the air and steam supply to the producer as well as the velocity of the air through the fuel bed, and of course the rate of combustion in the hearth, and the heat generated depends upon this velocity.

Air and Steam Requirements.—Let us first consider the quantity of air that would be required to gasify the combustible elements in a fuel if no steam were used. Knowing the chief combustible elements requiring to be gasified, are fixed carbon and sulphur, it is the oxygen requirements for the reduction of these elements to a gaseous state which require consideration. Under the best theoretical conditions of gasification about 5 lbs. of the fixed carbon per 100 lbs. of fuel are completely burned to carbon dioxide, due to the reversible reactions that take place in the producer, the remaining portion of the fixed carbon is burned to carbon monoxide, and the sulphur is burned to sulphur dioxide. Every pound of carbon burned to carbon monoxide requires 1·33 lbs. of oxygen for its combustion, liberating 4,450 B.Th.U's. of heat in the process. Every pound of carbon burned to carbon dioxide requires 2·66 lbs. of oxygen for its combustion, liberating 14,500 B.Th.U.'s of heat in the process. Every pound of sulphur burned to sulphur dioxide requires 1 lb. of oxygen for its combustion, liberating 4,000 B.Th.U.'s of heat in the process. As atmospheric air has to be used for supplying the oxygen required for combustion, its composition being by weight 23 per cent. of oxygen, weighing ·0842 lbs. per cu. ft., and 77 per cent. of nitrogen, weighing ·074 lbs. per cu. ft., for every pound of oxygen supplied the air brings with it 3·348 lbs. of nitrogen, an inert and useless gas for combustion purposes, but which is always bound to be there so long as air has to be used for supplying the oxygen necessary for combustion.

Assuming the following coal analysis and working out the necessary calculations at 60°F. and 30 ins. mercury will help to make the foregoing quite clear.

Fixed carbon, 59·52 per cent. ; sulphur, 1·07 per cent. ; volatiles, 33·7 per cent. ; moisture, 2·6 per cent. ; Ash, 3:11 per cent. ; oxygen brought in by coal, 14·09 per cent., this is included in volatiles, moisture and ash given.

NOTE.—There will be a slight error in the calculations due to not knowing the amount of hydrogen brought in by the coal, but as it is only a small amount compared to the rest of the constituents it can be neglected, and assume that the whole of the oxygen is absorbed in combustion, and that 5 lbs. of carbon are burned to carbon dioxide.

Then for every 100 lbs. of this fuel gasified there are :—

54·52 lbs. of C burned to CO which requires—
$$(54·52 \times 1·33) = 72·5116 \text{ lbs. of O}$$

5·00   ,,   C   ,, CO_2 which requires—
$$(5·00 \times 2·66) = 13·3 \quad ,, \quad O$$

1·07   ,,   S   ,, SO_2 which requires—
$$(1·07 \times 1·00) = 1·07 \quad ,, \quad O$$

Therefore total O required   ...   ...   86·8816 lbs.

Less O brought in by fuel   ...   ...   14·09   ,,

Leaving total O to be supplied by air   72·7916 lbs.

And N brought in by air would be $(72·8 \times 3·348) = 243·7344$ lbs.
Therefore weight of air required   (N+O).
$$(72·7916 + 243·7344) = 316·526 \text{ lbs.}$$
Taking 13 cu. ft. of air as weighing 1 lb. The volume of air required per 100 lbs. of fuel would be $(316·526 \times 13) = 4114·838$ cu. ft.

Say about 41 cu. ft. per pound of fuel.

Now the weight of the respective gases and ash obtained from the gasification of 100 lbs. of fuel with air would be :—

54·52 C+72·5116 O   ...   =   127·0316 lbs. of CO

5·00 C + 13·3 O ...   ...   =   18·3   ,, CO_2

33·7 Volatiles distilled   ...   =   33·7   ,,   Volatiles

243·7344 N   ...   ...   =   243·7344   ,,   N

1·07 S+1·07 O ...   ...   =   2·14   ,, SO_2

2·6 moisture converted
steam   ...   ...   =   2·6   ,, H_2O

427·506 lbs. of gases.
3·11 lbs. of ash.

Total gas and ash   ...   430·616 lbs.

The heat liberated in the process would be :—

54·52 lbs. of C burned to CO liberates—
$$(4,450 \times 54·52) = 242,614 \text{ B.Th.U's.}$$

5·00   ,,   C   ,, CO_2 liberates—
$$(14,500 \times 5·00) = 72,500 \quad ,,$$

1·07   ,,   S   ,, SO_2 liberates—
$$(4,000 \times 1·07) = 4,280 \quad ,,$$

Total heat liberated   319,394   ,,

Assuming that 8 per cent. of the total heat evolved is lost by radiation, conduction, etc., then the total heat units left to be taken up by the gas and ash at the moment of gasification would be :—

$$(319,394 - (319,394 \times \cdot 08)) = 293,842 \cdot 48 \text{ B.Th.U's.}$$

The temperature of the gases would be the total heat units available, divided by the weight of the gases, etc., produced, multiplied by their mean specific heat at that temperature thus :—

Heat units available   = 293,842·48 B.Th.U's.
Weight of gas and ash   = 431 lbs.
Mean specific heat of gases, etc.   = ·3 B.Th.U's. per lb.

Therefore temperature of gases $= \dfrac{293,842 \cdot 48}{431 \times \cdot 3} = 2,272°$ Fah.

It is therefore obvious, that the temperature of the outgoing gases when the producer is worked with air alone is far too high, and would bring about the serious losses in efficiency and quality of gas as before mentioned. To overcome these troubles and to bring the temperature of the outgoing gases down to about 1,200°F., which is about the most efficient temperature to work at, steam is used to regulate the temperature of the combustion zone which at the same time supplies a portion of the oxygen required for combustion. This has the double advantage of liberating hydrogen, a highly combustible gas, in the reaction and reducing the proportion of nitrogen necessarily present, thus producing a gas of smaller weight per unit volume but of richer quality as regards heating value.

The proportion of steam that can be used in gas producers will vary with the type and condition of the producer, also with the type of blower, nature of fuel, and the purpose for which the gas is to be used. In gas producers gasifying non-caking bituminous coals and producing gas suitable for use in iron and steel works furnaces, the best results are obtained when 10 parts of steam to 90 parts of air are used. As the specific gravity of steam is ·6218 compared with air, this would mean that 10 per cent. by volume of steam is about 6 per cent. by weight, or in every 100 lbs. of mixture, 6 lbs. are steam and 94 lbs. are air. When steam comes into contact with incandescent carbon the steam is decomposed into its elements oxygen and hydrogen, the Oxygen combining with the carbon to form carbon monoxide, and liberating the hydrogen, thus :—

$$C + H_2O = CO + 2H$$
$$\text{or } 12 + 18 = 28 + 2$$
$$\text{or } 6 + 9 = 14 + 1$$
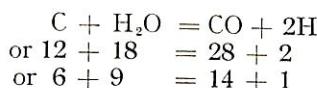
Therefore 6 lbs. of carbon are oxidised for each pound of hydrogen that is set free.

This action is endothermic in its nature, more heat being absorbed in dissociating the hydrogen from the oxygen in the water vapour, than is given out by the combustion of the carbon with the oxygen to form carbon monoxide. Thus the thermal action consists of two distinct steps.

(1) Formation of carbon monoxide which evolves heat.

(2) Decomposition of water vapour which absorbs heat.

2. Heat absorbed $62,000 \times 1$ = 62,000 B.Th.Us.

1. Heat evolved $4,450 \times 6$ = 26,700   ,,

$$\text{Difference} \quad \ldots \quad 35,300 \quad ,,$$

Therefore heat absorbed per lb. of carbon burned by steam
$$35,300 \div 6 = 5,883 \cdot 3 \text{ B.Th.Us.}$$

From this it is obvious that as all the heat for gasifying the combustible elements has to be supplied by those elements themselves, the amount of steam that can be used is limited, otherwise the temperature of the producer would fall so low that the reactions would cease altogether.

As carbon forms the greatest percentage of the combustible elements in fuels, the proportion given with relation to the carbon consumed would be as follows, thus :—
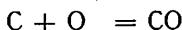
$$C + O = CO$$
$$\text{or } 12 + 16 = 28$$
$$\text{or } 3 + 4 = 7$$

4 lbs. of oxygen are required for the combustion of 3 lbs. of carbon to carbon monoxide, and since air contains 23 per cent. of oxygen by weight the quantity of air required to burn 1 lb. of carbon to carbon monoxide
$$= (4 \times 100) \div (3 \times 23) = 5 \cdot 8 \text{ lbs.}$$
Therefore 1 lb. of air would burn $(1 \div 5 \cdot 8) = \cdot 17$ lbs. of carbon.

$$\text{also } C + H_2O = CO + 2H$$
$$\text{or } 12 + 18 = 28 + 2$$
$$\text{or } 6 + 9 = 14 + 1$$

Thus 9 lbs. of steam will be required to burn 6 lbs. of carbon to carbon monoxide, or $(9 \div 6) = 1 \cdot 5$ lbs. of steam per lb. of carbon.

Therefore 1 lb. of steam would burn $(1 \div 1 \cdot 5) = \cdot 67$ lbs. of carbon, the proportion in a mixture of 100 lbs. being

6 lbs. steam multiplied by $\cdot 67 = 4 \cdot 02$ lbs. of carbon burned by steam.

94 ,, air   ,, $\cdot 17 = 15 \cdot 98$,,   ,,   ,, air.

In average practice, for every 5 lbs. of carbon consumed, 4 lbs. are burned by air and 1 lb. is burned by steam. In other words, the steam used should be 20 per cent. of the weight of the carbon consumed, the steam supplying 25 per cent. of the total oxygen required. The steam has to be carried into the producer with the air, and it is known that air can take up moisture or water-vapour in suspension in definite quantities, which depend upon the saturation temperature. As 4 lbs. or 52 cu. ft. of air have to carry 1 lb. of water vapour, therefore every cubic foot of air carries $(1 \div 52) = \cdot0192$ lbs. of water vapour, and the temperature of saturation to enable it to do this is 178° F. See Appendix. (In practice, the saturation temperature is usually kept between 110°F. and 130°F.)

The use of steam has also other advantages, keeping the clinker soft and porous and thereby allowing free access for the blast to the fuel, and moistening the ash and keeping the combustion away from the grates and blowing tuyeres, thus protecting them. It also prevents fine ash being blown into the combustion zone and fusing with the walls of the producer.

A clearer idea of the chemical and thermal reactions occurring in the gas producer may be obtained by working out a numerical example, which at the same time will illustrate the method of calculation. Taking a bituminous coal of known chemical analysis, for which is known also the chemical analysis of the gas obtained when gasified in a producer under actual working conditions, it is possible to find the best theoretical gas that could be made. If we then compare it with the actual gas obtained, it is possible to trace the whole of the chemical and thermal actions that take place in the producer. It has been shown that the volatile hydrocarbons are obtained by the process of distillation, therefore all that is left to be considered is the gasification of the fixed carbon and sulphur in the coal. The whole of the heat for the gasification has to be supplied by the fixed carbon in the fuel, also, as before mentioned, a proportion of this fixed carbon will be consumed in the process, due to the reversible reactions that take place in the producer. As the heat of combustion of 1 lb. of carbon when burned to carbon monoxide is 4,450 B.Th.Us', which is about 30 per cent. of the whole heat available when it is completely burned to carbon dioxide, viz., 14,500 B.Th. Us., it follows that the original system starts with a loss of 30 per cent. in efficiency. This loss, however, can be largely reduced by using steam to supply some of the oxygen required for combustion, thereby gaining hydrogen as a combustible gas for some of the heat absorbed in its dissociation. A saving can also be effected by reducing the losses due to radiation and conduction to a minimum and using the gas hot, thereby conserving its sensible heat. It has also been shown that to keep the temperature of the working

zone and outgoing gases at their correct points, one-fourth of the oxygen required for combustion can be derived from the use of steam, leaving the other three-fourths to be supplied by atmospheric air.

Therefore, taking as the basis of the example coal of the following analysis charged into a producer and the accompanying analysis of the gas obtained when gasified.

Coal Analysis.			Gas Analysis.	
Constituent.	% by Weight.		Constituent.	% by Volume.
Fixed Carbon ...	59·52		Carbon dioxide ...	7·93
Volatiles	33·70		Carbon monoxide	20·93
Sulphur	1·07		Hydrogen ...	13·97
Oxygen	14·09		Methane	2·94
Moisture	2·60		Nitrogen	54·23
Ash	3·11		Combustible gases	37·84

Steam pressure at blower, 60 lbs. per sq. in.

Saturation temperature of blast, 140° F.

Proceeding to find the conditions prevailing under the best theoretical gasification of this coal, we find that, taking 100 lbs. as the amount gasified at 60° F., and 30 in. Hg., and referring to Charts Nos. 10, 11 ,12, which show the influence of temperature on the reactions, these point to the fact that it should be theoretically possible to make the gas free entirely from carbon dioxide if the temperature in the reaction zone be kept above (1,127° C.) (2,060° F.) but this is not possible, due to the cause previously stated. The best theoretical results are obtained when the gas contains from 2 to 3 per cent. by volume of carbon dioxide, which means that with all ordinary classes of coals, about 5 lbs. of the fixed carbon in the fuel per 100 lbs. of fuel are completely burned. On these assumptlons, then—

For every 100 lbs. of fuel gasified there are :—

54·52 lbs. of C. burned to CO, which requires—

$$(54·52 \times 1·33) = 72·5116 \text{ lbs. of O.}$$

5 ,, C. ,, CO_2 which requires

$$(5 \times 2·66) = 13·3 \text{ ,,}$$

1·07 ,, S. ,, SO_2 which requires

$$(1·07 \times 1·00) = 1·07 \text{ ,,}$$

Therefore total O. required ... 86·8816 lbs.

Less O. brought in by fuel ... 14·09 ,,

Leaving total O. to be supplied by air and steam   72·7916 lbs.

O. to be supplied by steam = 25 per cent. of O

$$= (72·7916 \div 4) \quad \ldots \quad \ldots \quad \ldots \quad 18·1979 \text{ ,,}$$

Leaving O. to be supplied by air   ...   ...   54·5937 lbs.

And N. brought in by air would be $(54·6 \times 3·348) = 182·8$ lbs.

Therefore weight of air required = (N + O)

$$(182·8 + 54·6) = 237·4 \text{ lbs.}$$

Taking that 13 cu. ft. of air weighs 1 lb. at 60° F—

Then volume of air required per 100 lbs. of fuel would be—

$$(237·4 \times 13) = 3086·2 \text{ cu. ft.}$$

say about 31 cu. ft. per lb. of fuel.

Also 18·2 lbs. of O. from steam liberates $(18·2 \div 8) = 2·275$ lbs. of H.

Therefore weight of steam required per 100 lbs. of fuel would be :

$$(18·2 + 2·275) = 20·475 \text{ lbs.}$$

say about ·21 lbs. per lb. of fuel.

The weight of gases per 100 lbs. of fuel would be :—

54·52 C + 72·5116 O	... ... =	127·0316	lbs. of CO
5 C + 13·3 O	... ... =	18·3	,, CO_2
33·7 volatiles distilled	... ... =	33·7	,, volatiles
182·8 N	... =	182·8	,, N
1·07 S + 1·07 O	... ... =	2·14	,, SO_2
2·6 moisture converted into steam =		2·6	,, H_2O
2·275 H	... =	2·275	,, H

$$368·8466 \text{ lbs. gases}$$
$$3·11 \text{ ,, ash}$$

Total gases and ash   ...   ...   371·9566 lbs.

The volume of gases per 100 lbs. of fuel would be :—

127·0316 lbs of CO $\times$ 13·55 cu. ft. ... ... =	1721·35	cu. ft.
18·3 ,, $CO_2 \times$ 8·60 ,, ... =	157·38	,,
33·7 volatiles $\times$ 23·32 ,, ... =	785·88	,,
2·275 ,, H $\times$ 189·70 ,, ... =	431·57	,,
182·8 ,, N $\times$ 13·50 ,, ... =	2467·8	,,
2·14 ,, $SO_2 \times$ 6·00 ,, ... =	12·84	,,
2·6 ,, $H_2O \times$ 26·00 ,, ... =	67·6	,,

Total volume   ...   .   5644·42   ,,

Tabulating results thus :—

Weight of gas in lbs.	Volume of gas in cu. ft.	% by volume.	Gas.
127·0316	1721·35	30·5	CO
18·3	157·38	2·7	CO_2
33·7	785·88	13·9	Volatiles
2·275	431·57	7·7	H_2
182·8	2467·8	43·7	N_2
2·14	12·84	·3	SO_2
2·6	67·6	1·2	H_2O
368·8466	5644·42	100·00	

The total combustible gases (CO + volatiles + H)

$$(30·5 + 13·9 + 7·7) = 52·1 \text{ per cent.}$$

Total energy in gas from 100 lbs. of fuel :—

127·0316 lbs. of CO burned to CO_2

$$(127·0316 \times 4325) = 549411·67 \text{ B.Th.U's}$$

33·7   ,,   volatiles burned to CO_2 and H_2O

$$(33·7 \times 20000) = 674000 \text{ ,,}$$

2·275   ,,   H burned to H_2O

$$(2·275 \times 62000) = 141050 \text{ ,,}$$

Total ...   .   1364461·67   ,,

Total energy per 100 lbs. of coal fed into producer :—

59·52 lbs. of C burned to CO_2

$$(59·52 \times 14500) = 863040 \text{ B.Th.U.'s.}$$

33·7   ,,   volatiles burned to CO_2 and H_2O

$$(33·7 \times 20000) = 674000 \text{ ,,}$$

1·07   ,,   S burned to SO_2

$$(1·07 \times 4000) = 4280 \text{ ,,}$$

20·473   ,,   steam with 1100 B.Th.U.'s

$$(20·473 \times 1100) = 22520·3 \text{ ,,}$$

Total energy...   ...   ...   1563840·3   ,,

From the foregoing calculations the best theoretical results from this coal would be as follows :—

$$\text{Efficiency of producer} = \frac{1364461·67 \times 100}{1563840·3} = 87·25 \text{ per cent.}$$

$$\text{Cubic ft. of gas per lb. of coal} = \frac{5644·42}{100} = 56·4442 \text{ cu. ft.}$$

Lbs. of gas per lb. of coal $\quad = \dfrac{368 \cdot 8466}{100} \quad = \quad 3 \cdot 688 \text{ lbs.}$

Energy in gas per lb. of coal $\quad = \dfrac{1364461 \cdot 67}{100} \quad = 13644 \cdot 41 \text{ B.Th.U.'s}$

Cubic ft. per lb. of gas $\quad = \dfrac{5644 \cdot 42}{368 \cdot 8466} \quad = \quad 15 \cdot 3 \text{ cu. ft.}$

Energy per cu. ft. of gas $\quad = \dfrac{1364461 \cdot 67}{5644 \cdot 42} \quad = \quad 241 \cdot 7 \text{ B.Th.U.'s}$

Theoretical thermal actions, assuming there is no loss of heat whatever :—

Heat energy given out in producer or exothermic actions :—

$54 \cdot 52$ lbs. of C burned to CO $(54 \cdot 52 \times 4450)$ = 242614 B.Th.U.'s

$5 \quad$ „ $\quad$ C $\quad$ „ $\quad$ CO$_2$ (5×14500) = 72500 „

$1 \cdot 07 \quad$ „ $\quad$ S $\quad$ „ $\quad$ SO$_2$ $(1 \cdot 07 \times 4000)$ = 4280 „

$20 \cdot 473 \quad$ „ $\quad$ steam 1100 B.Th.U.'s

$\qquad\qquad\qquad (20 \cdot 473 \times 1100) \quad = 22520 \cdot 3$ „

Total energy $\quad \ldots \quad \ldots \quad \ldots \quad$ 341914·3 „

This equals $\dfrac{341914 \cdot 3 \times 100}{1563840 \cdot 3} = 21 \cdot 86$ per cent. of the total energy of fuel and steam used in the producer.

Heat energy absorbed or endothermic actions :—

Mean specific heat of gases at 1200° Fah. (See Appendix.)

Gases.	Weight of gases in lbs.	×	Specific heat of gases at 1,200° F. per lb.	=	B.Th.U's. Total. per deg. F.
CO	127·0316	×	·2622	=	33·3077
CO$_2$	18·3	×	·2777	=	5·0819
Volatiles ...	33·7	×	·6412	=	21·6084
H	2·275	×	3·686	=	8·3856
N	182·8	×	·2636	=	48·1861
SO$_2$	2·14	×	·2062	=	·4412
H$_2$O	2·6	×	·628	=	1·6328
	368·8466				118·6437

then $118 \cdot 6437 \div 368 \cdot 8466 = \cdot 322$ *Mean specific heat.*

Sensible heat in gases leaving producer at 1200° F., 368·8466 lbs. × ·322 sp. ht. × (1200° –60°) = 135396·2 B. Th.U.'s.

Now, 20·473 lbs. of steam are used, and knowing that 1 lb. of steam will burn ·67 lbs. of carbon to carbon monoxide, therefore the carbon consumed by the steam will be (20·473 × ·67) = 13·71691 lbs. Also knowing that for every pound of carbon that is consumed by steam there are 5883·3 B.Th.U.'s of heat lost in dissociating the steam, the heat absorbed in dissociating the steam will be :—

5883·3 B.Th.U.'s × 13·7 lbs. = *80601·21 B.Th.U.'s.*

The temperature of the combustion zone is 2060° F., and temperature of gases is 1,200° F., therefore the solid portion of the fuel has to be raised (2,060 – 1,200°) = 860° F. further in temperature.

Solid portion of fuel (59·52C+1·07S+3·11 ash) = 63·7 lbs.

Specific heat of coal at 2,060° F. = ·201+ (·00006 × 2060) = ·324.

Then heat absorbed by solid fuel is :—

63·7 lbs. × ·324 Sp. Ht. × (860° – 60°) F. = *16511·04 B. Th. U.'s.*

Also 237·4 lbs. of air are used, and this requires a further 860° F. rise in temperature to bring it up to the temperature of the combustion zone, and as the specific heat at 2,060° F. = ·271.

Therefore heat absorbed by air will be :—

237·4 lbs. × ·271 Sp. Ht. × (860° – 60°) F.=*51468·32 B.Th.U.'s.*

Also 20·475 lbs. of steam are used, and this requires a further 860° F. rise in temperature to bring it up to the temperature of the combustion zone, and as the specific heat of steam at 2,060° F. = ·7644, the heat absorbed by steam will be :—

20·475 lbs. × ·7644 Sp. Ht. × (860° – 60°) F.=*12520·872B.Th.U's.*

Also there are 2·6 lbs. of moisture, which required converting into steam at atmospheric pressure, and as the total heat in steam at atmospheric pressure = (212° – 60°)+966=1,118 B.Th.U.'s per lb., the heat absorbed in converting moisture in to steam will be:—

1,118 B.Th. U.'s × 2·6 lbs. = *2,906·8,B.Th.U.'s.*

Tabulating the foregoing results thus :—

Sensible heat in gases	...	...	135396·2	B.Th.U.'s.
Heat absorbed in dissociating				
	steam	... ...	80601·21	,,
,,	,, by solid part of fuel		16511·04	,,
,,	,, air ...	... ...	51468·32	,,
,,	,, steam	... ...	12520·872	,,
,,	,, moisture ...	...	2906·80	,,
	Total heat absorbed	...	299404·442	,,

Total heat evolved	...	341914·3	B.Th.U.'s.
,, ,, absorbed	...	299404·442	,,

Leaving heat for losses by radiation, etc.   ...   .   42509·858   ,,

Which is $\dfrac{42509 \cdot 858 \times 100}{341914 \cdot 3} = 12 \cdot 4$ per cent. of the total heat evolved, and which is rather more than the 8 per cent. which is usually assumed, and shows that sufficient heat has been generated in the system to meet all requirements

Having considered the best theoretical gasification for the sample of coal taken it will be interesting to analyse the actual results that were obtained and then form a comparison. To do this it is necessary to work backwards from the gas analysis, but first of all it is necessary to find the total carbon in the coal. Therefore assuming that 45 per cent. of the volatiles by weight are carbon, as the ultimate analysis of the coal is not known, then for 100 lbs. of coal the carbon content will be the sum of the fixed carbon and the carbon from the volatiles thus :—

$$(33 \cdot 7 \times \cdot 45) + 59 \cdot 52 = 74 \cdot 685 \text{ lbs.}$$

Find weight of carbon in 100 cu. ft. of gases thus :—

Carbon containing gas in cu. ft.	Weight in lbs. of gas.	Carbon ratio by weight.	Weight of carbon in gas in lbs.
CO ...	20·93	1·545	12/28	·662
CO₂ ...	7·93	·922	12/44	·251
CH₄ ...	2·94	·126	12/16	·094
Total carbon in 100 cu. ft. of gas			1·007 lbs.

Therefore the cu. ft. of gas per lb. of coal would be :—
$$(74 \cdot 685 \div 1 \cdot 007) = 74 \cdot 165 \text{ cu. ft.}$$

And from 100 lbs. of coal :—
$$(74 \cdot 165 \times 100) = 7416 \cdot 5 \text{ cu. ft. of gas.}$$

The volume of the respective gases from 100 lbs. of coal would be :—

$7416 \cdot 5 \times \cdot 2093 =$	1552·274 cu. ft. of	CO
$7416 \cdot 5 \times \cdot 0793 =$	588·128 ,,	CO₂
$7416 \cdot 5 \times \cdot 1397 =$	1036·085 ,,	H
$7416 \cdot 5 \times \cdot 0294 =$	218·045 ,,	CH₄
$7416 \cdot 5 \times \cdot 5423 =$	4021·968 ,,	N

Total   7416·500 cu. ft. of gases.

The weight of the respective gases from 100 lbs. of coal would be :—

$$1552 \cdot 274 \div 13 \cdot 55 = 114 \cdot 559 \text{ lbs. of CO}$$
$$588 \cdot 128 \div 8 \cdot 60 = 68 \cdot 387 \quad ,, \quad CO_2$$
$$1036 \cdot 085 \div 189 \cdot 70 = 5 \cdot 461 \quad ,, \quad H$$
$$218 \cdot 045 \div 23 \cdot 32 = 9 \cdot 350 \quad ,, \quad CH_4$$
$$4021 \cdot 968 \div 13 \cdot 50 = 297 \cdot 293 \quad ,, \quad N$$

Total   495·050 lbs. of gases.

Oxygen supplied to producer per 100 lbs. of coal :—

Oxygen supplied by air $(297 \cdot 293 \div 3 \cdot 348)$ = 88·797 lbs.
,,   ,,   steam $(5 \cdot 461 \times 8)$ = 43·688 ,,

,,   ,,   air and steam   ...   132·485 lbs.
Adding oxygen carried by coal ...   ...   14·09 ,,

Total oxygen supplied   ...   ...   146·575 lbs.

Steam supplied to producer per 100 lbs. of coal :—
(43·688 lbs. oxygen + 5·461 lbs. hydrogen) = 49·149 lbs. of steam.

Air supplied to producer per 100 lbs. of coal :—
(88·797 lbs. oxygen + 297·293 lbs. nitrogen) = 386·09 lbs. of air,
or $386 \times \dfrac{13}{100} = 50 \cdot 18$ cu. ft. of air per lb. of coal.   Say 50 cu. ft.

Amount of carbon which must have been consumed to give the above weights of carbon monoxide and carbon dioxide in gas :—

Carbon burned to carbon monoxide :—
(49·167 lbs. of C) + (49·167 × 1·33 lbs. of O) = 114·559 lbs. of CO

Carbon burned to carbon dioxide :—
(18·685 lbs. of C) + (18·685 × 2·66 lbs. of O) = 68·387 lbs. of CO_2

Tabulating results obtained thus :—

Process.	Weight in lbs.	Volume in cu. ft.	% by Volume.
49·157 lbs. of carbon burned to CO	114·559	1552·274	20·93
18·685 lbs. of carbon burned to CO_2	68·387	588·128	7·93
9·35 lbs. of volatiles distilled ...	9·35	218·045	2·94
Hydrogen liberated from steam	5·461	1036·085	13·97
Nitrogen brought in with air ...	297·293	4021·968	54·23
Combustible gases	—	—	37·84
	495·050	7416·500	100·00

From these results it can be seen that the total carbon gasified in the process was :—

	49·167	lbs. of carbon burned to carbon monoxide				
	18·685	,,	,,	,,	,,	dioxide
total	67·852	,,	,,	gasified		
less	59·52	,,	,,	originally fixed in coal		
leaves	8·332	,,	,,	gained from some other source		
also	33·7	lbs. of volatile matter was in original coal				
and	9·35	,,	,,	only distilled		
leaving	24·35	,,	,,	consumed or lost.		

Now the 8·332 lbs. of carbon could only have been obtained by splitting up a portion of the volatile matter therefore :—

$$8·332 + \left(\frac{8·322 \times 55}{45}\right) = 18·515 \text{ lbs. of volatiles consumed.}$$

or $(24·35 — 18·515) = 5·835$ lbs. of the total combustible matter in the coal was completely lost.

Total energy in gas from 100 lbs. of coal :—

114·559 lbs. of CO burned to CO_2

				$(114·559 \times 4325)$	=495,467	B.Th.U's
9·35	,,	CH_4	,,	CO_2 and H_2O		
				$(9·35 \times 23500)$	=219,725	,,
5·461	,,	H	,,	H_2O		
				$(5·461 \times 62000)$	=338,582	,,
				Total ...	1,053,774	B.Th.U's

Total energy per 100 lbs. of coal fed into producer :—

59·52	lbs. of C burned to CO_2	$(59·52 \times 14500)$	=863,040	B.Th.U's	
33·7	,,	volatiles burned to CO_2 and H_2O			
		$(33·7 \times 20000)$	=674,000	,,	
1·07	,,	S burned to SO_2 $(1·07 \times 4000)$	= 4,280	,,	
49·149	,,	steam at 1,100 B.Th.U's. per lb.			
		$(49·149 \times 1100)$	= 54,064	,,	
		Total ...	1,595,384	B.Th.U's	

Then :—

$$\text{Efficiency of producer} = \frac{1053774 \times 100}{1595384} = 66 \text{ per cent.}$$

$$\text{Cubic feet of gas per lb. of coal} = \frac{7416 \cdot 5}{100} = 74 \cdot 165 \text{ cu. ft.}$$

$$\text{Lbs. of gas per lb. of coal} = \frac{495 \cdot 050}{100} = 4 \cdot 95 \text{ lbs.}$$

$$\text{Energy in gas per lb. of coal} = \frac{1053774}{100} = 10537 \cdot 74 \text{ B.Th.U's}$$

$$\text{Cubic feet per lb. of gas} = \frac{7416 \cdot 5}{495 \cdot 050} = 14 \cdot 9 \text{ cu. ft.}$$

$$\text{Energy per cu. ft. of gas} = \frac{1053774}{7416 \cdot 5} = 142 \text{ B.Th.U's.}$$

Thermal actions :—

Heat energy given out in producer or exothermic action :—

49·167 lbs. of C burned to CO (49·167×4450) =218,793 B.Th.U's
18·685 „ C „ CO_2 (18·685×14500) =270,932 „
1·07 „ S „ SO_2 (1·07×4000) = 4,280 „
49·149 „ steam at 1,100 B.Th.U's.
  (49·149×1100) = 54,064 „

Total energy ... 548,069 B.Th.U's

this equals $\dfrac{548069 \times 100}{1595384} = 34 \cdot 3$ per cent. of the total heat energy of the coal and steam used.

Now, 49·149 lbs. of steam were used, and, knowing that 1 lb. of steam will burn ·67 lbs. of carbon to carbon monoxide, therefore the carbon consumed by the steam will be :—

$$(49 \cdot 149 \times \cdot 67) = 33 \text{ lbs.}$$

Also knowing that for every pound of carbon that is consumed by the steam there are 5883·3 B.Th.U.'s of heat lost in dissociating the steam, then the heat absorbed in dissociating the steam will be :

$$(5883 \cdot 3 \text{ B.Th.U.'s} \times 33 \text{ lbs.}) = 194{,}149 \text{ B.Th.U.'s.}$$

Also there were 2·6 lbs. of moisture which required converting into steam at atmospheric pressure, and as the total heat of steam at atmospheric pressure $= (212° - 60°) + 966 = 1{,}118$ B.Th.U.'s per lb., then heat absorbed in converting moisture into steam will be :—

$$(1{,}118 \text{ B.Th.U.'s} \times 2 \cdot 6 \text{ lbs.}) = 2906 \cdot 8 \text{ B.Th.U.'s.}$$

Also, allowing **8** per cent. of the total heat generated as lost by radiation, etc., then this loss will be (605367 × ·08) = *48429 B.Th.U.'s.*

Tabulating these results thus :—

Heat absorbed in dissociating steam	...	194,149 B.Th.U.'s.
,,	,,	by moisture	...	...	2,097 ,,
,,	,,	,, radiation, etc.	...	48,429 ,,
	Total	...	...	...	...	244,675 ,,
	Total heat evolved	...	...	548,069 ,,
	,, absorbed	...	...	244,675 ,,

Leaving heat for raising temperature of combustion zone and sensible heat in gas   303,394   ,,

The ratio between the heat absorbed in the combustion zone and the heat remaining sensible in the gases leaving the producer is 2 to 3. Therefore $\dfrac{303394 \times 3}{5} = 182036 \cdot 4$ B.Th.U.'s, which will be represented in the sensible heat of the gases, and, assuming that the specific heat of the gases will be ·32, and knowing that 495 lbs. of gas was liberated, then the temperature of the gas leaving the producer will be :—

$$\frac{182036 \cdot 4}{495 \times \cdot 32} = 1149° \text{ F.},$$

which is just about the right temperature.

Now, (303394–182036·4) = 121357·6 B.Th.U.'s as available heat for raising the temperature of the combustion zone, and knowing that the following represents the constituents that have to absorb this heat, it is possible to get the temperature of the combustion zone.

Carbon in fuel	...	...	...	...	59·52 lbs.
Sulphur ,,	...	...	...	...	1·07 ,,
Ash ,,	...	...	...	...	3·11 ,,
Air used ...	...	...	...	...	50·18 ,,
Steam used ...	...	...	...	...	49·149 ,,
Total ...	...	...	...	...	163·019 ,,

Assuming the mean specific heat of the above to be ·40, then the temperature of the combustion zone above the temperature of the outgoing gases will be :—

$$\frac{121357 \cdot 6}{163 \times \cdot 40} = 1,861° \text{ F.}$$

Then temperature in combustion zone would be $(1,149° + 1,861°)$ $= 3,010°$ F., which is far too high, and brings about the conditions mentioned hereafter.

The following is a balance sheet showing the comparison between the theoretical and actual gasification of the sample of coal taken :—

COMPARISON BETWEEN THEORETICAL AND ACTUAL GASIFICATION OF COAL SAMPLE AT 60°F. AND 30″HG.

Item.	Theoretical.	Actual.
Gas per cent. by volume :—		
Carbon monoxide—CO	30·5	20·93
Carbon dioxide—CO_2	2·7	7·93
Methane and Volatiles—CH_4 and etc. ...	13·9	2·94
Hydrogen—H	7·7	13·97
Nitrogen—N	43·7	54·23
Sulphur dioxide—SO_2	·3	—
Water vapour—H_2O	1·2	—
Percentage of combustible gases	52·1	37·84
Cubic ft. of air used per lb. of fuel	30·86	50
Lbs. of steam used per lb. of fuel	·20475	·49149
Temperature of outgoing gases (°F.)	1200°	1149°
,, combustion zone (°F.)	2060°	3010°
Total heat energy put into producer per lb. of coal (B.Th.U's.)	15638·403	15953·84
Total heat energy in gas per lb. of coal (B.Th.U's.)	13644·61	10537·74
Efficiency of producer	87·25	66·00
Cu. ft. of gas per lb. of coal	56·442	74·165
Lbs. of gas per lb. of coal	3·688	4·95
Cubic ft. per lb. of gas	15·3	14·9
Heat energy per cu. ft. of gas (B.Th.U's.) ...	241·7	142·0
Exothermic action percentage of total heat energy	21·86	34·3
Endothermic action percentage of total heat energy evolved	87·6	92·0
Per cent. loss by radiation, etc.	12·4	8·0

From the foregoing figures of comparison between the theoretical and actual gasification of the coal sample various deductions can be made allowing for any slight error in the calculations due to having to assume 45 per cent. of carbon in the volatiles. This had to be assumed as the ultimate analysis of the coal was not known. The first item of note is that the saturation temperature was given as 140° F., at which temperature the 5,000 cu. ft. of air that were required would only carry 40·7 lbs. of steam (see Appendix, Table 3). Therefore one assumes that the $(49·149 - 40·7) = 8·449$ lbs. of steam were due to evaporation of water from the water bosh, on account of the high temperature of the ash from the combustion zone or the high hydrogen content was due to splitting up the volatiles, probably the latter. Secondly, far too much air and steam was used, thus causing the producer to be overblown, which is

shown by the very lean gas produced, viz., 74·165 cu. ft. per lb. of coal. This overblowing is also the cause of the low percentage of carbon monoxide and methane, etc., also the cause of the high carbon dioxide and hydrogen contents in the gas, as it causes the volatiles to be split up and the gases to be burned by the excess air inside the producer. The gasification efficiency is also low, viz., 66 per cent., and this is only to be expected when 34·3 per cent. of the total energy of the fuel and steam used is given out in the producer, which accounts for the high temperature in the combustion zone, viz., 3,010° F. Although this gas shows 37·84 per cent. of combustible gases with a combustible energy of 142·0 B.Th.U.'s per cu. ft. in its composition, it would not be suitable for open hearth steel melting furnaces, as lean gas with a low percentage of carbon monoxide in its composition only propagates a very short flame on its combustion, which reduces the radiative effect.

It is imperative that when the gas is required for open hearth steel melting furnaces that it should contain as high a percentage of carbon monoxide as possible, with hydrogen content not more than half carbon monoxide, or in any case not more than 11 per cent. by volume, and from 40 to 45 per cent. of total combustibles in its composition.

By working and comparing in this way it is possible to find out from the various coal and gas analysis just what is happening in the producer, thus enabling corrections to be made in working so as to get the best results. If the ultimate analysis of the fuel and the carbon remaining in the ash were known, and if it were possible to get a complete analysis of the distillation gases, then a more accurate comparison could be made. In any case, the percentage of error in the method used is small, and is a good practical guide to what is taking place.

METHOD OF DESIGNING WATER BOTTOM GAS PRODUCERS. AND DETAILS.

Having considered the chemical and thermal actions that take place, in addition to the general conditions regarding gas producer working, it is now possible to investigate the principles governing design and the fixing of the various proportions to give definite outputs.

As before mentioned, gas producers can be designed to gasify any type or class of fuel that contains carbon. This being so, the first and chief factor in the design is the correct area of the hearth, as upon this depends the rate of gasification and the diameter of the producer. This area is governed by the type and class of fuel to be gasified, and the most economical rate of combustion per sq. ft. of hearth for that particular type and class of fuel. Like other items of

plant, the best rate of gasification is obtained when the producer works under the conditions for which it was designed, although in actual practice sometimes this is not possible on account of having to use fuels from localities other than the regular source of supply. It never pays to work with too high a blast pressure or to drive the producer too fiercely, for the various reasons mentioned in the section dealing with the thermal conditions of gasification. The following are about the best rates of combustion for various grades of fuel when gasified in continuous water bottom producers, hand fed, the blast being supplied through central blowing tuyeres. The central blowing tuyere is taken because it gives the best results in practice :

Bituminous coal up to 20 per cent. fines and up to 10 per cent. ash, 20 lbs. per sq. ft. of hearth per hour.

Bituminous coal from 20 per cent. to 40 per cent. fines and from 10 to 20 per cent. ash, 15 lbs. per square ft. of hearth per hour.

Bituminous coal from 40 to 60 per cent. fines and from 20 to 30 per cent. ash, 10 lbs. per sq. ft. of hearth per hour.

First class lignite and briquettes, 25 lbs. per sq. ft. of hearth per hour.

Inferior qualities of lignites, 20 lbs. per sq. ft. of hearth per hour.

Anthracite and coke, 20 lbs. per sq. ft. of hearth per hour.

Therefore area of producer inside brickwork in sq. ft. will be :—

$$\frac{\text{Required gasification in lbs. per hour.}}{\text{Rate of combustion per sq. ft. of hearth per hour.}}$$

It is worth noting in passing that one large producer is cheaper per sq. ft. of gas producing area than a number of small producers, and that large producers will give a slightly better rate of combustion per sq. ft. of hearth than small ones. There is a limit to the size of hearths, for if made too large they become difficult to work, also there is a danger of the CO_2 in the gas on the extreme edges of the hearth not being properly reduced to CO. The maximum size should be about 12 ft. inside the brickwork, but more often it is about 10 ft., which would be about 15 cwts. per hour producer when gasifying good English coal, and consuming 20 lbs. of coal per sq. ft. of hearth per hour. If the producers were fitted with revolving boshes and mechanical feeds the above rates of combustion per sq. ft. of hearth per hour could be increased 25 per cent.

The next consideration is what is the most economical depth of fuel bed to secure complete reduction, as this governs the heights of the producers. It also depends upon the type and class of fuel to be gasified and the velocity of the air blast, dusty fuels requiring less depth than loose, coarse fuels. The following are about the correct depths of fuel beds for the complete reduction of various classes of fuels :—

1 in. coke or anthracite	...	...	...	30 ins.
$1\frac{1}{2}$ ins. ,,	,, ...	...	...	... 45 ,,
$2\frac{1}{4}$,, ,,	,, ...	...	...	... 72 ,,
$\frac{3}{4}$,, bituminous coal ...	...	...	... 22 ,,
Run-of-mine bituminous coal	·	...	48 to 60 ,,

The next item is the gas outlet from the producer. This outlet is most conveniently made at the side of the producer, and near the top, the bottom of the outlet being kept 12 to 18 ins. above the normal level of the fuel bed, and of such an area that it will easily convey the gases away. It should never be less than $\frac{1}{18}$ the area of the producer hearth, which is equivalent to a carrying capacity for hot gases of 200 lbs. of coal per hour per sq. ft. of section.

In practice this area is usually kept about $\frac{1}{13}$ to $\frac{1}{14}$ the area of the producer hearth. This rule also holds good for all hot gas flues. In the gas outlet flue an isolating valve of the mushroom type should be placed to allow the producer to be shut off from the main gas flue, and this valve should have the same area as the gas outlet flue. In the gas outlet flue and the valve box, cleaning out doors should be provided, so that any accumulations of soot, etc., can be easily raked out. The position of these cleaning-out doors is shown in Fig. 9, the door in the valve box also being used as an explosion door to relieve the pressure should any explosion take place inside the producer.

The level of the fuel bed is kept from 2 ft. 6 ins. to 3 ft. above the level of the water bosh, so as to ensure the top of the blowing tuyere being covered by a protecting layer of ash. Thus the height of a producer for bituminous coals from the level of the water bosh to the springing of the crown will be :—

(30 ins. to 36 ins.) + (48 ins. to 60 ins.) + (12 ins. to 18 ins.) + diameter of outlet ; depending upon the size of the producer.

Round the circumference of the producer and about 3 ft. above the level of the water bosh, four sight holes should be provided, about 2 ins. diameter, with a swinging flap made of cast iron or steel plate on the outside of the producer casing. These holes are to enable a watch to be kept on the combustion zone by the men in charge and also to allow them to insert bars to clear the clinker from the grate. In the lower part of the producer casing, just above the water bosh, cleaning-out doors should be provided, about 24 ins. wide by 18 ins. high, large enough for a man to get through, the opening in the brickwork lining of the producer being bricked up with a loose stopping. These doors are to facilitate cleaning out when the producer is shut down and also to provide a means of access when any repairs require to be done to the producer lining as well as to facilitate lighting up the producer. The doors and door frames are usually made of cast iron, the frames being cast to fit

the shape of the casing and bolted to same, the doors being either hinged to the frames or left loose and held in position by means of clamps and screws. On the top of the producer and in the centre the charging or feeding hopper is fixed, being of cast iron of double conical section fitted with a cast iron lid on the top to keep it gas-tight, while in the bottom is fitted the conical bell which distributes the fuel over the hearth, the bell being lowered and raised by means of a balanced hand lever. The capacity of the feeding or charging hopper should be about one-fifth of the producer gasifying capacity per hour, allowing 2 cu. ft. capacity per cwt. of fuel.

The distributing bell should be part of a cone with its sides at an angle of 45 degrees, and the diameter at the bottom should be equal to one-sixth the internal diameter of the producer to get uniform distribution of the fuel over the hearth.

The hopper should be mounted on a cast iron foundation ring, and held in position by means of four or six clamps, the foundation ring being built into the brickwork of the producer. This is for hand-fed producers. If mechanical feeding hoppers are used they require to be fitted with a revolving bell, arranged so that they distribute the fuel according to the consumption required.

Between the edge of the foundation ring and the inside edge of the producer brickwork six or eight poking-hole blocks should be fitted in such a position that they give access to the whole of the hearth, especially the sides. These blocks are usually of cast iron with a hole $1\frac{3}{4}$ ins. to 2 ins. diameter through them, and built into the producer brickwork, the hole being filled with a loose cast iron plug or ball to keep it gastight. Figs. 13, 14, 15, 16 show a typical design for each of these details.

The next detail and one of great importance is the steam nozzle and blowing tuyere, Fig. 17, which are usually designed so that (the energy derived from) the high pressure steam is used for carrying in the air that is required. As fuels vary considerably in composition these parts have to be designed to cover a fairly wide range of supply, the finer regulation being controlled by inserting a steam stop valve in the steam supply pipe immediately above the steam nozzle. In practice it is usual to make the steam nozzle capable of passing ·75 lbs. of steam per lb. of fuel, and carrying with it an air supply of 40 cubic ft. per lb. of fuel as the maximum when the producer is for gasifying a good class of bituminous fuel. It is always preferable to work out the air and steam requirements from the analysis of the fuel that is to be used by the method shown above in the section dealing with this item, allowing about 30 per cent. more air than that theoretically calculated. The steam requirements vary considerably as caking fuels and slack require more steam than the better grades of fuel, but the figure given, viz., ·75 lbs. per lb. of fuel, should cover all requirements.

CHARGING HOPPER & FOUNDATION RING.

FIG. 13.

HAND LEVER

LID

HINGE

HOPPER

CLAMPS

FOUNDATION RING.

BELL.
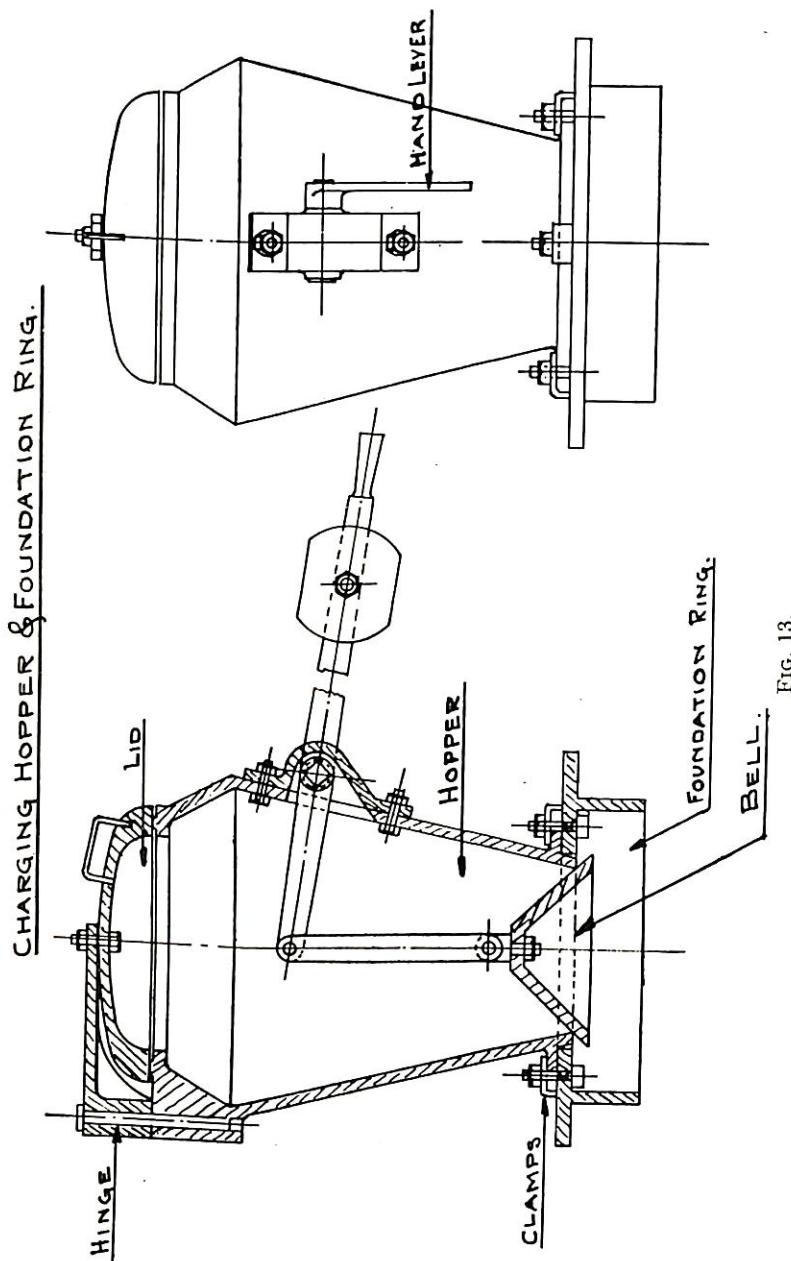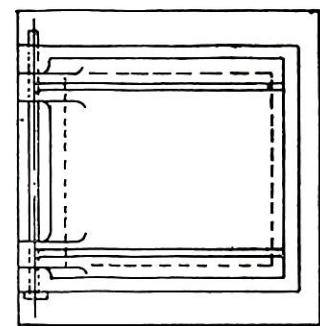
Explosion Doors 15"x15"
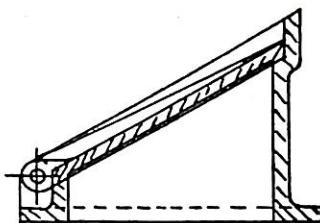
Fig. 15.
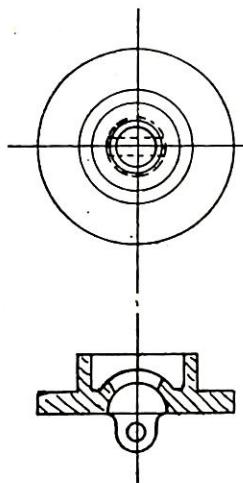
Poking Hole Blocks & Plugs.

Fig. 16.
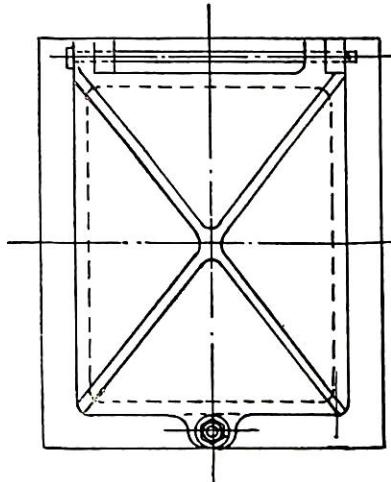
Cleaning Doors for Producer 24"x18"
" " Gas Tubes 12"x 9"

Fig. 14
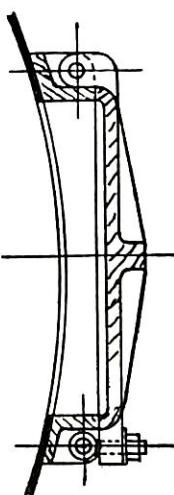
STEAM JET BLOWER & CENTRAL BLOWING TUYERE

STEAM NOZZLE

STRAP 2" x ¼"
FLAT BAR

STEAM PIPE

STEAM VALVE

STEAM NOZZLE

BLOWER INLET.

BLOWER NECK.

BLAST OPENINGS

BLAST OPENINGS

TUYERE.

BLOWER

BLOWER OUTLET.

DRAIN

CONNECTING PIPE

FOOT.
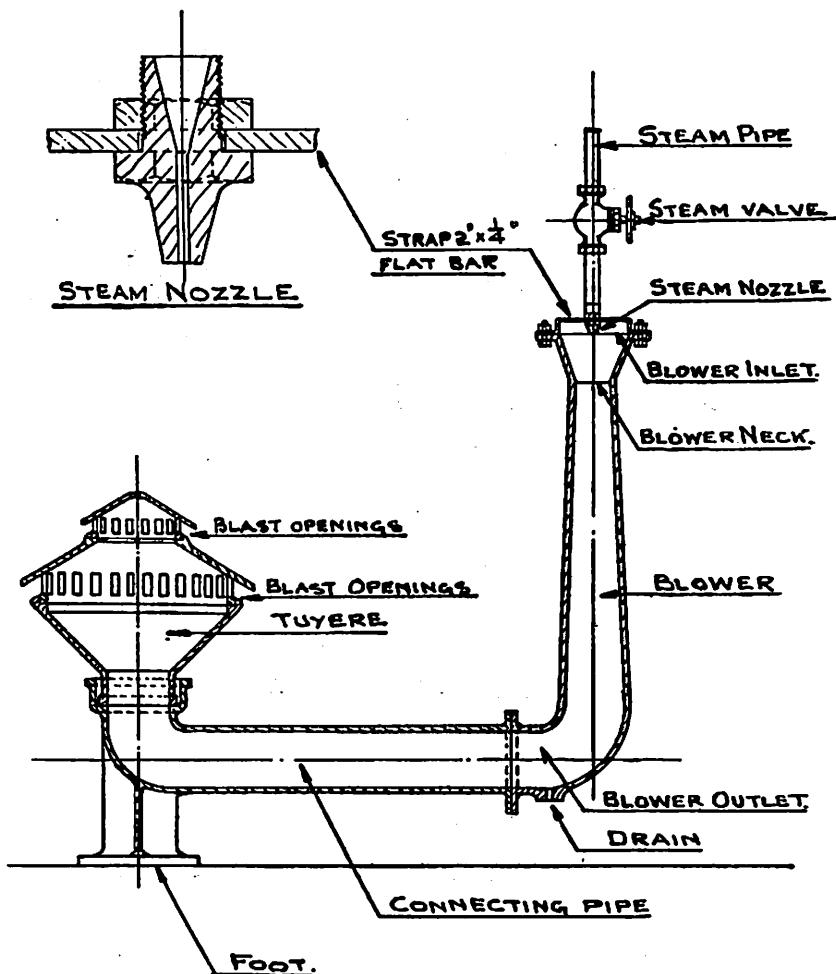
FIG. 17.

The method of finding the proportions for the steam nozzle, blower pipe and blowing tuyere for a steam jet blower are as follows, and to make the method clear an example will be given. Assuming a steam jet blower necessary for a 10 cwts. per hour producer, the proportions would be :—

Coal to be gasified per hour $(10 \times 12) = $ 1,120 lbs.

,,   ,,   minute $(1,120 \div 60)$ ... $=$ $18 \cdot 66$ lbs.

Air requirements per minute $(18 \cdot 66 \times 40) = 746 \cdot 4$ cu. ft. at 60° F.

,,   ,, $(746 \cdot 4 \div 13) = 57 \cdot 4$ lbs.   ,,

Assuming steam pressure used is 75 lbs. per sq. in. absolute, then this steam would occupy $5 \cdot 68$ cu. ft. per lb. (see steam tables).

Steam requirements per minute $(18 \cdot 66 \times \cdot 75)$ ... $= 14$ lbs.

,,   ,, $(14 \times 5 \cdot 68)$ ... $= 79 \cdot 5$ cu. ft.

The velocity of the blast that is required to burn 10 cwts. of fuel per hour at the rate of 20 lbs. per sq. ft. of hearth per hour would be :

Coal consumed per second $(1,120 \div 3,600) = \cdot 311$ lbs.

Area of hearth $(1,120 \div 20)$ ... $= 56$ sq. ft. or 8ft. 6 in. dia.

Effective area for passage of gases is taken at 5 per cent. of total area.   Therefore nett effective area $(56 \times \cdot 05) = 2 \cdot 8$ sq. ft.

Assuming that 1 lb. of fuel produces 70 cu. ft. of gas at 60° F., then gas produced per second $(\cdot 311 \times 70) = 21 \cdot 77$ cu. ft. at 60° F. Increase in volume of hot gas at combustion temperature, viz. 2,060° F. will be :—

$$\frac{21 \cdot 77 \times (2,060° + 460°)}{(60° + 460°)} = 106 \cdot 673 \text{ cu. ft. per sec.}$$

Then the required velocity will be $(106 \cdot 673 \div 2 \cdot 8) = 38$ ft. per second.   The draught at the blower to give this velocity will be :—

Head to give the above velocity $(38^2 \div 64)$ ... $= 22 \cdot 531$ ft.

Then pressure per sq. ft. $(22 \cdot 53 \times \cdot 076)$ ...   ... $= 1 \cdot 7$ lbs.

Draught in inches water gauge $= \dfrac{1 \cdot 7 \times 12}{62 \cdot 4}$ ... $= \cdot 32$ ins.W.G.

Diameter of Steam Nozzle.—The design of a steam nozzle for a desired weight of flow is determined by the area of the throat (the smallest cross section) of the nozzle.   From Rankin's experiments it was found that the pressure at the throat will be about $\cdot 58$ of the initial pressure whenever the ratio of the final pressure to the initial pressure is less than that quantity, and for ratios greater than $\cdot 58$ the throat pressure is the same as the final pressure.   Therefore—

Initial pressure absolute ...   ...   75 lbs. per sq. in.

Final   ,,   ,, ...   15   ,,

And as $\dfrac{15}{75}$ is less than $\cdot58$, the pressure at the throat will be $75 \times \cdot58 = 43\cdot5$ lbs. per sq. in.

Now total heat in steam at 75 lbs. absolute $= 1{,}181$ B.Th.U.'s.

And   ,,   ,,   43$\cdot$5   ,, $= 1{,}171$,,

Therefore difference is kinetic energy at throat $=$ 10   ,,

Volume of 1 lb. of steam at 43$\cdot$5 lbs. absolute $= 9\cdot68$ cu. ft.

And steam required is 14 lbs. per minute—

Therefore volume of steam per second $= \dfrac{14 \times 9\cdot68}{60} = 2\cdot25$ cu. ft.

Weight of 1 cu. ft. of steam at 43$\cdot$5 lbs. absolute $= \cdot103$ lbs.

Therefore weight of steam per second $= 2\cdot25 \times \cdot103 = \cdot23$,,

Kinetic energy at throat $= 10$ B.Th. U.'s—

Joules equivalent $= 772$ ft. lbs. $= 1$ B.Th.U.

Then velocity through throat $= \sqrt{\dfrac{64 \times 10 \times 772}{\cdot23}} = 1{,}469$ ft. per sec.

And area of throat $= \dfrac{2\cdot25 \times 144}{1{,}469} = \cdot22$ sq. ins.

Which is equivalent to a nozzle $\frac{17}{32}$ ins. diameter.

Instead of the above, Rankin's approximate formula could have been used, viz., $A = \dfrac{W \times 70}{P}$

Where A $=$ Area at throat in sq. ins.

W $=$ Weight of steam in lbs. per second discharged.

P $=$ Absolute initial steam pressure in lbs. per sq. in.

70 $=$ Constant.

Diameter of Blower Inlet.—It was shown that the draught at the blower requires to be $\cdot32''$ W.G. or an equivalent velocity of 38 ft. per second, therefore the area required to pass 746$\cdot$4 cu. ft. of air per minute will be :—

$$\frac{746\cdot4 \times 144}{60 \times 38} = 48\cdot188 \text{ sq. ins.}$$

which is equivalent to an inlet $7\frac{7}{8}$ ins. diameter.

Diameter at the Neck of Blower.—Ratio between weight of steam and air to be passed per minute is—

(57$\cdot$4 to 14) or (4$\cdot$1 to 1)

Now the action of a steam jet depends upon the following four rules :—

1. The quantity of air delivered by a steam jet depends upon the extent of surface contact between the steam and air, up to the limits of exhaustion or compression the jet is capable of producing.

2. The quantity of air delivered per minute within effective limits is in the inverse proportion to the weight of air acted upon, better results being obtained in exhausting than in compressing.

3. The maximum degree of vacuum or pressure attainable increases in direct proportion to the steam pressure employed.

4. The limits of air pressure attainable with a given pressure of steam are the same in compressing or exhausting, within the limits of a perfect vacuum in the latter case.

Therefore by Rule 2 the ratio 4·1 to 1 is the ratio between the areas of the air and steam space at the neck of the blower.

Also the ratio between the theoretical velocity of the steam into the atmosphere (see Table 2 in Appendix) and the velocity through the neck of the blower is—

$$(2,425 \text{ to } 38) \text{ or } (63 \cdot 8 \text{ to } 1)$$

Therefore the area of the steam stream at neck of blower is—

$$(\cdot 0787 \times 63 \cdot 8) = 5 \cdot 021 \text{ sq. ins.}$$

which is equivalent to a stream $2\frac{1}{2}$ ins. diameter.

Then the total area at the neck of the blower will be :—

$$(5 \cdot 021 \times 4 \cdot 1) = 20 \cdot 5861 \text{ sq. ins.}$$

which is equivalent to $5\frac{1}{8}$ ins. diameter.

Diameter of Outlet from Blower.—Weight of steam carried per cu. ft. of air is :—

$$(14 \div 746 \cdot 4) = \cdot 0187 \text{ lbs.}$$

Referring to aqueous vapour table in Appendix, it is seen that this weight of steam per cu. ft. of air gives a saturation temperature of 176° F., and a tension pressure of 7 lbs. per sq. in., the resulting volume of 1 cu. ft. of saturated air being 2·5 cu. ft. Therefore the area of the outlet from the blower will require to be 2·5 times the area of the blower neck to maintain uniform velocity, and will be :—

$$(20 \cdot 5861 \times 2 \cdot 5) = 51 \cdot 46528 \text{ sq. ins.}$$

which is equivalent to $8\frac{1}{8}$ ins. diameter.

Area of Outlets from Blowing Tuyere.—Assuming that the saturated air will reach a temperature equal to the temperature in

the combustion zone, viz., 2,060° F., then the volume of the satu-
rated air at this temperature compared to its volume at the blower
outlet will be :—

$$(2,060° + 460°) \div (176° + 460°) = 3 \cdot 9$$

Therefore the total area of the outlets from the blowing tuyere,
whether made a series of slots or a continuous ring opening, will
be :—

$$(51 \cdot 465 \times 3 \cdot 9) = 200 \cdot 7135 \text{ sq. ins.}$$

Also the diameter of the tuyere head should be made about one-
third the diameter of the inside of the producer to ensure the blast
penetrating to the extreme edges of the fuel bed.

Length of Blower Inlet from Tip to Neck.—NOTE.—The mouth of
the steam nozzle should be kept on the same level as the top of the
inlet to the blower.

The steam area at the neck of the blower was found to be
5·021 sq. ins., and as the co-efficient of expansion for dry saturated
steam expanding adiabetically is 1·135, then the length of the
blower inlet from top to neck will be :—

$$(5 \cdot 02 \times 1 \cdot 135) = 5 \cdot 7 \text{ ins.}$$

Length of Blower from Neck to Centre of Outlet.—The area of the
outlet from the blower was found to be 51·46 sq. ins., and, using the
same co-efficient of expansion as above, then the length of the blower
from the neck to the centre of the outlet will be :—

$$(51 \cdot 46 \times 1 \cdot 135) = 58 \cdot 4071 \text{ ins.}$$

At the lowest point of the blower a drain hole should be provided for
draining away any water that may accumulate, due to the con-
densation of steam.

Diameter of Steam Supply Pipe.—The diameter of the steam
supply pipe to the steam nozzle should be large enough to convey
the required amount of steam at a velocity of 80 ft. per second, and
should have a regulating steam stop valve placed immediately above
the nozzle.

In the case of the example this pipe would be :—

$$\frac{1,120 \times \cdot 75 \times 144}{3,600 \times 80} = \cdot 432 \text{ sq. ins. area or } \tfrac{3}{4} \text{ in. diameter.}$$

Pressure of Blast in Blowing Tuyere.—Assuming that the pressure
of the outgoing gases is kept at 1 in. water gauge, then—

Equivalent velocity due to this head is $8 \sqrt{\dfrac{62 \cdot 4 \times 1}{12 \times \cdot 076}}$

$$= 66 \text{ ft. per second.}$$

Mean gas velocity through fuel bed is   ...   = 38   ,,
Therefore equivalent velocity at tuyere(66+38)= 104   ,,

Which equals a pressure of—

$$\frac{104^2 \times \cdot 076 \times 12}{64 \times 62 \cdot 4} = 2 \cdot 47 \text{ ins. water gauge.}$$

Gas Producer Linings.—As mentioned previously, the mild steel shell or casing of the gas producer requires lining throughout with a hard quality of firebrick which has been well burned in the kiln, and which is capable of resisting abrasion due to the falling fuel and pokers striking against the brickwork walls. This lining should never be less than 9 ins. thick, and should be laid with the least possible amount of fireclay mortar in the joints. These remarks also apply to the linings of all hot gas tubes and flues, except that $4\frac{1}{2}$ to 3 ins. of brickwork is sufficient thickness for all hot gas tubes. The types of bricks used for the producer lining are known in the trade as circulars and crowns, and for the tube linings as side arch.

The dome to form the roof of the producer should be struck from a radius never less than the internal diameter of the producer hearth, and likewise should never be less than 9 ins. thick, the types of bricks used for this purpose being known as crowns. Special fireclay blocks require to be built into the roof for supporting the poking hole castings. These blocks are usually made in halves, and have the poking hole through them opened out towards the lower side to give greater angularity to the pokers when poking down the fuel bed. In the centre of the roof a special ring of fireclay blocks is built to support the foundation ring for the charging hopper. These also should have their lower sides chamfered off so that the fuel can distribute itself properly from the charging bell into the producer hearth without any obstruction. It usually takes from 30 to 36 of these blocks to form a ring. The roof of the producer should be levelled up to the height of the charging platform with a hard quality brick, the best class of bricks for this purpose being what are known as blue bricks. Special fireclay blocks are also required to be built into the producer lining to form the sight holes in the combustion zone ; and are usually made in halves and have the sight holes through them opened out on the inside to allow a wider range of view.

Water bottom producers of the fixed-grate type and similar to those shown on Figs. 3, 4, and 5, have the bosh for receiving the ash built underneath them in brickwork, which proves very satisfactory. They should be built of blue bricks laid in cement, the brickwork being bedded on concrete backing. Blue bricks are best for this purpose as they are not only hard in structure, but are not easily affected by the acids in the ash. These boshes should be from 2 ft. 3 ins. to 2 ft. 6 ins. deep, and should extend across the producer at this depth until clear of the water seal plate, the ends being then tapered up to ground level at an angle of 20° to form lutes. This is to allow plenty of room for the man to get his shovel underneath the water seal plate to extract the ash. This is most important, for if there be not sufficient room the man will not be able to get his
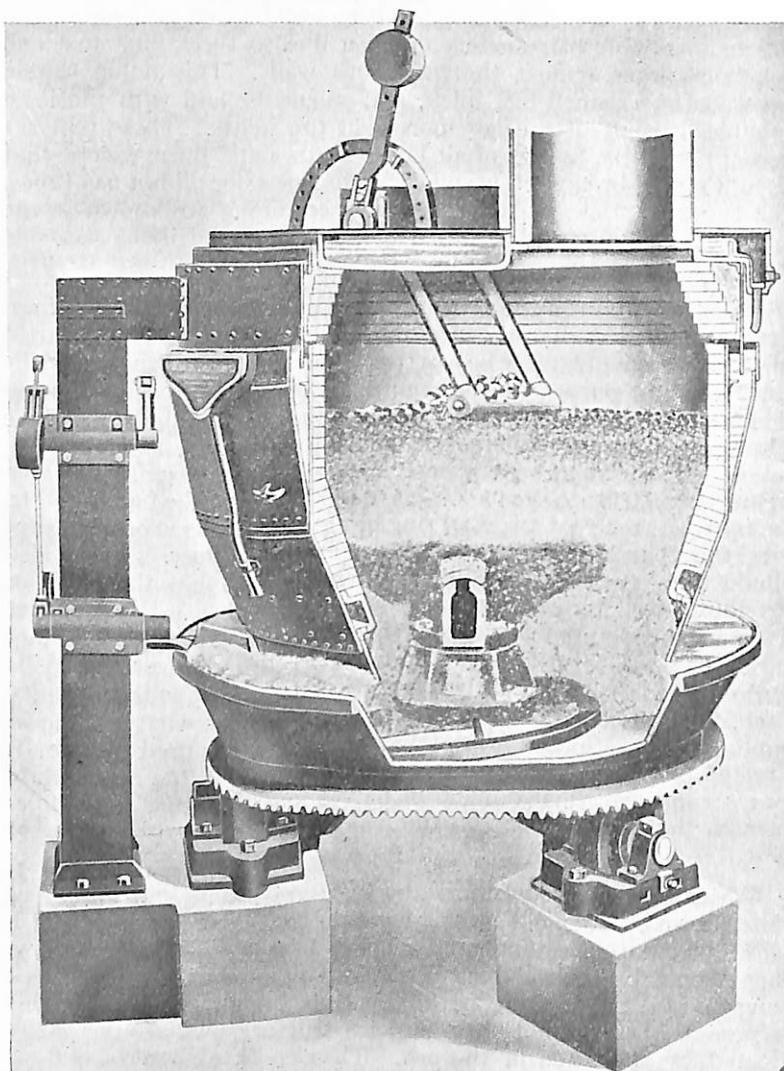
"MORGAN" MECHANICAL PRODUCER.

FIG. 18.

Feeding device that
does not choke.

Poker that is positive in
action and operates within
the fuel bed.

Mechanical
Ash discharge

blower

—WELLMAN MECHANICAL PRODUCER—
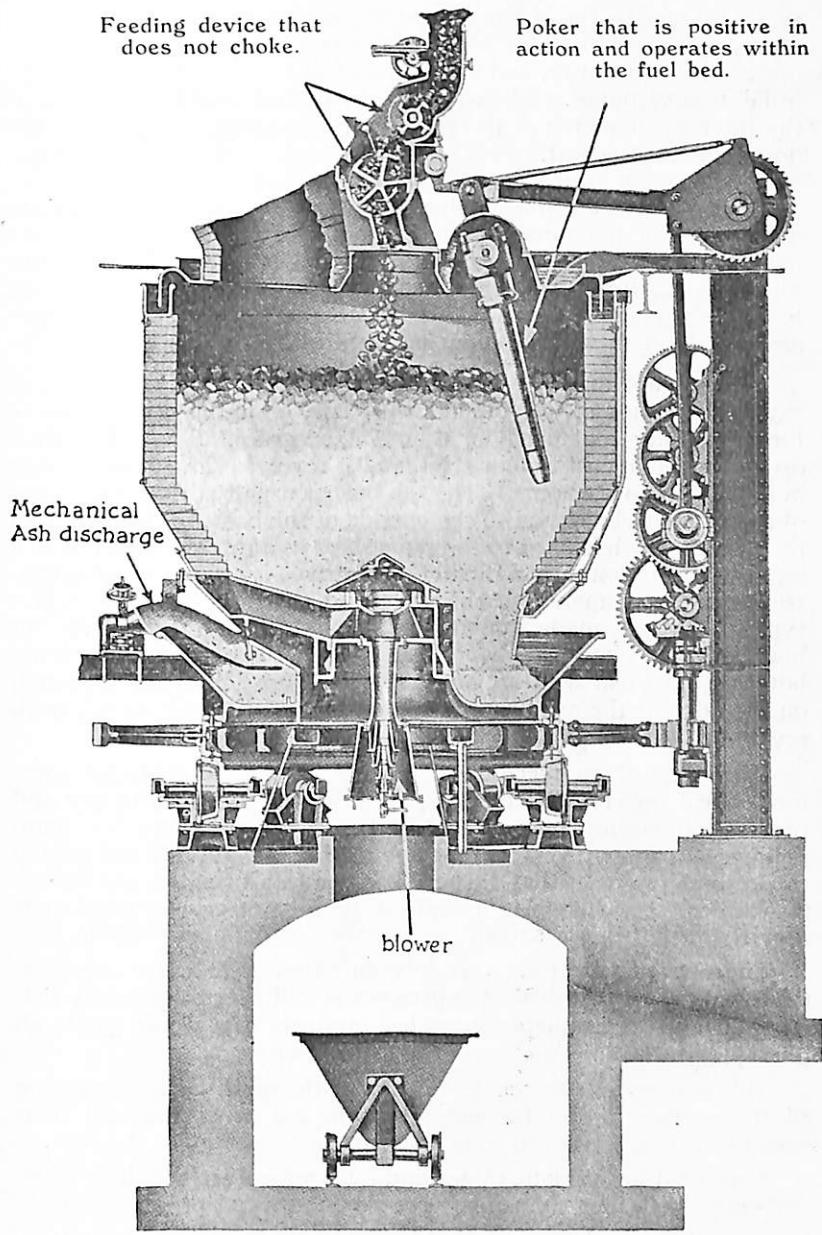
FIG. 19

shovel to the centre of the producer, and thus will only clean the edges, with the inevitable result that a cone of ash will form in the centre of the producer, and an unequal fuel bed develop with all the usual disadvantages. The width of the bosh should be the same as the internal diameter of the producer, especially that part of the bosh which is deepest.

Mechanical Producers.—Mechanical water bottom producers differ from the fixed grate water bottom producer in that the grate and ash bosh is made to revolve slowly. This is a decided advantage when caking fuels have to be used, as the revolving grate helps to keep the clinker broken up. Figs. 18 and 19 shows the arrangement of Morgan and Wellman mechanical producers respectively.

With regard to design, the methods given will apply throughout except that this type of producer will gasify about 25 per cent. more fuel per square foot per hour than a fixed grate. The ash bosh is usually made of cast iron or steel, and it revolves slowly about once in every four to six hours. The ash bosh is usually driven by means of a worm wheel fixed on to the outside of the bosh. This is driven by a worm which is fixed to the same shaft as a ratchet wheel, which receives its motion from a ratchet pawl driven by means of an eccentric from a continuous running overhead shaft. Producers of this type are usually made from 15 to 20 cwts. gasifying capacity per hour, and they require about 2 H.P. each to drive the revolving bottom. The ash is extracted automatically by inserting a plough on the edge of the ash bosh, which pushes the ash out as the bosh revolves.

With regard to mechanical feeding hoppers, revolving tops, mechanical pokers and agitators, these are all methods to try and prevent clinkering, uneven fuel bed and the necessity for hand poking. At present there is always a certain amount of hand poking to do, and provision has to be made for this even on top of the mechanical producer, also if uniform quality of gas production is required, the fuel bed should be disturbed as little as possible.

The above devices are certainly an attempt to overcome these troubles, but a great deal of experience is still necessary before it is possible to get a complete mechanical producer that would gasify all classes of fuels.

This now completes the description of the methods for designing all the various details for water bottom gas producers and their construction is clearly shown in the diagrams illustrating the text.

Appended are various tables and data which are required when making calculations concerning gas producers and producer gas.

Finally, the author hopes that his small effort on a most interesting and important subject to iron and steel works engineers and

draughtsmen will be of some use to his fellow craftsmen, and, if so, he will feel fully satisfied.

The author also wishes to thank all the firms who so kindly supplied the various drawings and particulars of the producers which are used to illustrate the text under their respective names, and which has helped in no small degree to make the paper interesting.

APPENDIX.

LIST OF CONSTANTS USED.

1 lb. of C. burned to CO requires 1·33 lbs. of O or 5·785 lbs.of air

1 ,,   C   ,, CO_2 ,,   2·66   ,,   O ,,   11·57   ,,

1 ,,   S   ,, SO_2 ,,   1·00   ,,   O ,,   4·35   ,,

Steam H_2O contains 1 part H to 8   parts O by weight.

Air   N+O ,,   1 ,, O ,, 3·348 ,, N   ,, or 23 per cent. O and 77 per cent. N.

,,   N+O ,,   1 ,, O ,, 3·762 ,, N by volume or 21 per cent. O and 79 per cent. N.

Volume of Gases at 60° F. and 30" Hg.

1 lb. of	air	N + O	...	13·00	cu. ft.
,,	carbon monoxide	CO ...	...	13·55	,,
,,	carbon dioxide	CO_2 ...	...	8·60	,,
,,	methane	CH_4	...	23·32	,,
,,	volatiles	$CmHn$	...	22·41	,, (approx.)
,,	ethylene	C_2H_4	...	13·46	,,
,,	hydrogen	H	...	189·70	,,
,,	nitrogen	N ...	...	13·50	,,
,,	oxygen	O ...	...	11·88	,,
,,	sulphur dioxide	SO_2 ...	...	6·00	,,

Heat evolved on Combustion at Constant Pressure.

1 lb. of C burned to CO evolves 4,450 B.Th.U.'s.

,,   C   ,, CO_2 ,,   14,500   ,,

,,   CO   ,, CO_2 ,,   4,325   ,,

,,   H   ,, H_2O ,,   62,000   ,,

,, CH_4 ,, CO_2 and H_2O evolves 23,500 B.Th.U's.

,,   S   ,, SO_2 evolves 4,000 B.Th.U.'s.

,, C_2H_4 ,, CO_2 and H_2O evolves 21,300 B.Th.U.'s.

,,   volatiles ,, CO_2 ,, H_2O ,,   20,000   ,, (approx.)

Specific Heats (Violle) (t = temperature in degrees F.).

Specific heat of Bituminous Coal $= ·201 \times (·00006 \times t)$.

,,   Coke $= ·203 \times (·00006 \times t)$.

,,   Carbon $= ·355 \times (·00006 \times t)$.

,,   Ash $= ·215 \times (·00006 \times t)$.

Volume of Gases.

The volume of a gas varies directly as the absolute temperatures

($t°$ F. + 460) = absolute temperature in ° F.

(t ° C. + 273) =   ,,   ,,   ° C.

TABLE 1.

MEAN SPECIFIC HEATS PER POUND OF GASES AT CONSTANT PRESSURE FROM 0° TO 2000° CENT.

(TH. BECKERT).

Temperature °Fah.	Temperature °Cent.	Air $N+O$	Oxygen O	Nitrogen N	Hydrogen H	Carbon Monoxide CO	Methane CH_4	Vapour H_2O	Carbon Dioxide CO_2	Sulphur Dioxide SO_2	Ethylene C_2H_4
32	0	·2375	·2175	·2438	3·4090	·2425	·5930	·4415	·1952	·1450	·3710
212	100	·2405	·2202	·2468	3·4516	·2455	·6004	·4702	·2079	·1544	·3951
392	200	·2434	·2229	·2499	3·4942	·2486	·6078	·4989	·2206	·1638	·4192
572	300	·2464	·2257	·2529	3·5369	·2516	·6152	·5276	·2333	·1733	·4434
752	400	·2494	·2284	·2560	3·5795	·2546	·6226	·5563	·2460	·1827	·4675
932	500	·2523	·2311	·2590	3·6221	·2576	·6300	·5880	·2586	·1921	·4916
1112	600	·2553	·2338	·2621	3·6647	·2607	·6375	·6137	·2713	·2015	·5157
1292	700	·2583	·2365	·2651	3·7073	·2637	·6449	·6424	·2804	·2109	·5398
1472	800	·2612	·2393	·2682	3·7500	·2667	·6523	·6711	·2967	·2204	·5640
1652	900	·2640	·2420	·2712	3·7926	·2698	·6597	·6998	·3094	·2298	·5881
1832	1000	·2672	·2447	·2743	3·8352	·2728	·6671	·7285	·3221	·2392	·6122
2012	1100	·2702	·2474	·2773	3·8778	·2758	·6745	·7572	·3348	·2486	·6363
2192	1200	·2731	·2501	·2804	3·9204	·2789	·6819	·7859	·3475	·2580	·6604
2372	1300	·2761	·2528	·2834	3·9631	·2819	·6893	·8146	·3602	·2675	·6846
2552	1400	·2791	·2556	·2865	4·0057	·2849	·6967	·8433	·3729	·2769	·7087
2732	1500	·2820	·2583	·2895	4·0483	·2879	·7041	·8720	·3855	·2863	·7328
2912	1600	·2850	·2610	·2926	4·0909	·2910	·7116	·9007	·3982	·2957	·7569
3092	1700	·2880	·2637	·2956	4·1335	·2940	·7190	·9294	·4109	·3051	·7810
3272	1800	·2909	·2665	·2987	4·1762	·2970	·7264	·9581	·4326	·3146	·8052
3452	1900	·2939	·2692	·3017	4·2188	·3001	·7338	·9868	·4363	·3240	·8293
3632	2000	·2969	·2719	·3048	4·2614	·3031	·7412	1·0155	·4490	·3334	·8534

TABLE 2.

TABLE GIVING THE THEORETICAL VELOCITY OF DRY SATURATED STEAM INTO
THE ATMOSPHERE AND INTO A VACUUM.

(*Practical Engineer Pocket Book.*)

Pressure of steam in pounds per square inch absolute.	Velocity in feet per second into the atmosphere.	Velocity in feet per second into a vacuum of 28″ mercury.
10	—	2,677
15	—	2,900
30	1,602	3,263
50	2,108	3,510
75	2,425	3,671
100	2,645	3,804
125	2,777	3,905
150	2,900	3,983
175	3,000	4,050
200	3,075	4,100
250	3,207	4,190

TABLE 3.
PRESSURE AND MASS OF SATURATED AQUEOUS VAPOUR.

Temperature.		Pressure in inches of Mercury.	Mass in pounds per cubic foot.	Total volume of Gas and Water Vapour resulting from saturating 1 cubic foot of Dry Gas at 0° and 30″ Hg. to $t°$.
°C.	°F.			
0	32·0	0·18	·000297	1·0060
1	33·8	0·19	·000317	1·0107
2	35·6	0·21	·000340	1·0144
3	37·4	0·22	·000364	1·0191
4	39·2	0·24	·000389	1·0228
5	41·0	0·26	·000416	1·0275
6	42·8	0·27	·000444	1·0312
7	44·6	0·29	·000474	1·0359
8	46·4	0·31	·000506	1·0407
9	48·2	0·34	·000540	1·0444
10	50·0	0·36	·000576	1·0491
11	51·8	0·38	·000613	1·0539
12	53·6	0·41	·000653	1·0587
13	55·4	0·44	·000695	1·0634
14	57·2	0·47	·000740	1·0682
15	59·0	0·50	·000787	1·0730
16	60·8	0·53	·000837	1·0778
17	62·6	0·57	·000889	1·0826
18	64·4	0·60	·000994	1·0884
19	66·2	0·64	·001002	1·0933
20	68·0	0·68	·001058	1·0981
21	69·8	0·73	·001127	1·1040
22	71·6	0·77	·001195	1·1099
23	73·4	0·82	·001266	1·1148
24	75·2	0·87	·001341	1·1207
25	77·0	0·93	·001420	1·1267
26	78·8	0·98	·001503	1·1327
27	80·6	1·04	·001590	1·1387
28	82·4	1·10	·001666	1·1447
29	84·2	1·17	·001777	1·1518
30	86·0	1·24	·001877	1·1578
31	87·8	1·31	·001977	1·1650
32	89·6	1·39	·002092	1·1722
33	91·4	1·47	·002207	1·1794
34	93·2	1·56	·002328	1·1866
35	95·0	1·65	·002740	1·1939
36	96·8	1·74	·002787	1·2023
37	98·6	1·84	·002825	1·2096
38	100·4	1·94	·002869	1·2181
39	102·2	2·05	·003020	1·2266
40	104·0	2·16	·003178	1·2363
41	105·8	2·28	·003343	1·2448
42	107·6	2·40	·003515	1·2545
43	109·4	2·53	·003694	1·2643
44	111·2	2·66	·003881	1·2788
45	113·0	2·81	·004076	1·2863
46	114·8	2·96	·004280	1·2974
47	116·6	3·11	·004481	1·3085
48	118·4	3·28	·004712	1·3208
49	120·2	3·44	·004942	1·3332

Temperature.		Pressure in inches of Mercury.	Mass in pounds per cubic foot.	Total volume of Gas and Water Vapour resulting from saturating cubic foot of Dry Gas at 0° and 30″ Hg. to t°.
°C.	°F.			
50	122·0	3·62	·005181	1·3468
51	123·8	3·81	·005429	1·3605
52	125·6	4·00	·005688	1·3742
53	127·4	4·19	·005957	1·3892
54	129·2	4·40	·006237	1·4054
55	131·0	4·63	·006527	1·4218
56	132·8	4·85	·006829	1·4394
57	134·6	5·09	·007143	1·4571
58	136·4	5·34	·007469	1·4761
59	138·2	5·59	·007789	1·4963
60	140·0	5·86	·008139	1·5179
61	141·8	6·14	·008521	1·5396
62	143·6	6·43	·008896	1·5639
63	145·4	6·73	·009313	1·5883
64	147·2	7·04	·009695	1·6152
65	149·0	7·37	·010115	1·6436
66	150·8	7·70	·010550	1·6733
67	152·6	8·05	·011001	1·7044
68	154·4	8·42	·011467	1·7381
69	156·2	8·79	·011591	1·7746
70	158·0	9·18	·012737	1·8137
71	159·8	9·59	·012967	1·8556
72	161·6	10·01	·013503	1·9002
73	163·4	10·45	·014056	1·9488
74	165·2	10·90	·014627	2·0002
75	167·0	11·37	·015218	2·0570
76	168·8	11·85	·015828	2·1179
77	170·6	12·36	·016459	2·1843
78	172·4	12·88	·017110	2·2574
79	174·2	13·41	·017782	2·3386
80	176·0	13·97	·018475	2·4268
81	177·8	14·55	·019192	2·5245
82	179·6	15·14	·019930	2·6344
83	181·4	15·76	·020694	2·7566
84	183·2	16·40	·021481	2·8939
85	185·0	17·05	·022293	3·0516
86	186·8	17·74	·023130	3·2298
87	188·6	18·44	·023993	3·4381
88	190·4	19·16	·024882	3·6792
89	192·2	19·91	·025799	3·9666
90	194·0	20·69	·026742	4·3102
91	195·8	21·49	·027714	4·7329
92	197·6	22·31	·028715	5·2596
93	199·4	23·16	·029746	5·9393
94	201·2	24·04	·030807	6·8433
95	203·0	24·95	·031899	8·1121
96	204·8	25·88	·033045	10·0170
97	206·6	26·84	·034177	13·1920
98	208·4	27·84	·035365	19·5440
99	210·2	28·86	·036587	38·6040
100	212·0	29·92	·037843	—

TABLE 4.

CALORIFIC POWER OF GASES. (By Berthelot.)

Gas.	At Constant Pressure.				At Constant Volume.			
	B.Th.U. per lb.		B.Th.U. per cu. ft.		B.Th.U. per lb.		B.Th.U. per cu. ft.	
	High.	Low.	High.	Low.	High.	Low.	High.	Low.
Carbon monoxide ... CO	4385	—	342·4	—	4367	—	340·9	—
Ethylene ... C_2H_4	21928	20527	1713·0	1603·0	21858	20457	1707·0	1597·0
Hydrogen ... H	62100	52290	347·1	292·3	61371	51561	343·0	288·2
Methane ... CH_4	24019	21566	1072·0	963·0	23897	21444	1067·0	958·0
Carbon ... C	14647·5	—	—	—	—	—	—	—

CALORIFIC POWER

The calorific power of a substance is the quantity of heat given out by the combustion of a unit mass, or volume of the substance, when burned at constant pressure or constant volume.   The products of combustion being cooled to the temperature of the atmosphere.

To find the nett calorific power of a sample of producer gas burned at constant pressure :—

Taking gas sample used in text and lower calorific values, gas per cent. by volume—

$$
\begin{aligned}
CO_2 &= \cdot 0793 & - & = & - \\
CO &= \cdot 2093 \times 342 \cdot 4 &= 71 \cdot 56432 & \text{B.Th. U.'s.} \\
H &= \cdot 1397 \times 292 \cdot 3 &= 40 \cdot 83431 & \text{,,} \\
CH_4 &= \cdot 0294 \times 963 \cdot 0 &= 28 \cdot 2122 & \text{,,} \\
N &= \cdot 5423 & - & = & -
\end{aligned}
$$

1·0000 cu. ft.	=140·61083 B.Th.U.'s.

If the gases were burned at constant volume, the calorific power would be slightly less.

CALORIFIC INTENSITY.

The calorific intensity or theoretical flame temperature of a substance is the temperature to which the products of combustion would be raised if the initial temperature was 32° F., and, assuming that all the heat evolved was taken up by the products of combustion,   The actual flame temperature will be slightly lower than that calculated, depending chiefly upon the amount of excess air used for combustion.

To find the calorific intensity of a sample of producer gas, taking the previous gas sample to illustrate method.   The nett calorific power was 140·61 B.Th.U.'s. per cu. ft., therefore the heat of combustion of 1 cu. ft. is 140·61 B.Th.U.'s, and the products of combustion from 1 cu. ft. of this gas will be :—

1. *Water Vapour.*

H_2O due to Hydrogen (H) ...   .   = ·1397 cu. ft.
H_2O ,,   Methane (CH_4)   ...   ...   = ·0588   ,,

Total	·1985 ,,

2. *Carbon Dioxide.*

CO_2 due to Carbon monoxide (CO)   ...   = ·2093 cu. ft.
CO_2 ,,   Methane (CH_4) ...   .   = ·0294   ,,
CO_2 present in Gas (CO_2)   ...   .   = ·0793   ,,

Total	·3180 ,,

3. *Nitrogen.*

    Oxygen required for combustion is :—

For Hydrogen (H)	= ·06985 cu. ft.
„ Carbon monoxide (CO)	= ·10465 „
„ Methane (CH_4)	= ·0588 „

          Total ... ... ·2333 „

The nitrogen in the air used for combustion is therefore—

    ·2333 × 3·76 ... ... = ·8772 cu. ft.
    Nitrogen present in gas ... = ·5423 „

          Total ... ... 1·4195 „

Therefore weight of products of combustion will be at 32° F. and 30″ Hg. :—

	% by volume.		Cubic feet per pound.		Weight of gas in pounds.
Water vapour ...	·1985	÷	19·3	=	·0102
Carbon dioxide ...	·318	÷	8·137	=	·0390
Nitrogen	1·4195	÷	12·773	=	·1111
Totals ...	1·9360 cu. ft. weighs			=	·1603 lbs.

Then—

$$\left\{ \begin{array}{l} \text{Weight of pro-} \\ \text{ducts of combus-} \\ \text{tion from 1 lb.} \\ \text{of gas in lbs.} \end{array} \right\} \times \left\{ \begin{array}{l} \text{Specific heat} \\ \text{of gases at} \\ \text{combustion} \\ \text{temperature} \end{array} \right\} \times \left\{ \begin{array}{l} \text{Combustion} \\ \text{temperature} \\ \text{in ° F.} \end{array} \right\}$$

        = Calorific power of gas per lb. in B.Th.U.'s.
    Therefore—

        ·1603 × sp. ht. × T ° F. = 140·61 B.Th.U.'s.

and, taking the specific heat of the products of combustion as ·355, then the calorific intensity of this gas is—

$$\frac{140·61}{·1603 \times ·355} = 2,471° \text{ F.}$$

    If the temperature of the gas or air, or both, be raised by the addition of any sensible heat, with any system of recuperation or regeneration, before combustion takes place, the temperature due to their average sensible heat must be added to the theoretically calculated calorific intensity to get the actual temperature of combustion.